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HANDBOOK
OF
MANUAL METAL-ARC WELDING
FOR
WELDERS

BUREAU OF INDIAN STANDARDS

MANUAL METAL-ARC WELDERS' HANDBOOK

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HANDBOOK
OF
MANUAL METAL-ARC WELDING
FOR
WELDERS

BUREAU OF INDIAN STANDARDS
MANAK BHAVAN, 9 BAHADUR SHAH ZAFAR MARG
NEW DELHI 110002

PRICE Rs 120·00

January 1965

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Edition 1 1965

Second Reprint DECEMBER 1991

UDC 621·791·75

Printed in India by Simco Printing Press, Delhi and
Published by the Bureau of Indian Standards, New Delhi 110002

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FOREWORD

Steel, which is a very important basic raw material for industrialization, had been receiving considerable attention from the Planning Commission even from the very early stages of the country's First Five-Year Plan period. The Planning Commission not only envisaged an increase in production capacity in the country, but also considered the question of even greater importance, namely, the taking of urgent measures for the conservation of available resources. Its expert committees came to the conclusion that a good proportion of the steel consumed by the structural steel industry in India could be saved if higher efficiency procedures were adopted in the production and use of steel. The Planning Commission, therefore, recommended to the Government of India that the Indian Standards Institution should take up a Steel Economy Project and prepare a series of Indian Standard Specifications and Codes of Practice in the field of steel production and utilization.

One of the subjects under the Steel Economy Project is that pertaining to the popularization of welding. As a result of intensive study made during the last few years and deliberations at numerous sittings of technical committees, a number of Indian Standards have been published in the field of welding. A complete list of Indian Standards published on welding is included in Appendix C. In addition to the publication of codes of practice and design standards, it was felt necessary that welders should be systematically trained in this country and that a handbook giving theoretical and practical information in simple language should also be made available to them for their reference purposes. With this object in view, an Indian Standard Code of Practice for Training and Testing of Metal Arc Welders (IS : 817-1957) and this handbook for welders have been prepared.

Other handbooks proposed to be published in the series in due course are expected to cover the following subjects:

a) Welding supervisors,

b) Gas welders, and

c) Welding engineers.

Production of sound and economic welds depends to a large extent on the welder himself. Thus, a trained welder with a fair amount of theoretical knowledge would be able to carry out welding jobs efficiently and economically.

A separate Indian Standard, namely, IS : 1181-1957 Qualifying Tests for Metal Arc Welders (Engaged in Welding Structures Other Than Pipes), has been published and it is proposed that similar qualification tests will also be prescribed for gas welding and for other specialized applications.

This handbook requires reference to The Carbide of Calcium Rules, 1937 with its subsequent amendments issued by the Government of India.

Metric system has been adopted in India and all values in this handbook have been given in this system. However, in Section 9, a test called 'Controlled Thermal Severity Test' has been described. In this test the dimensions have been specified in fps units as this test is a description of an experimental work carried out. For the sake of convenience, equivalent fps values of metric values used in the handbook are given in Appendix D.

This handbook, which has been processed by the Structural Welding Sectional Committee, SMDC 15, the composition of which is given in Appendix E, has been approved for publication by the Structural and Metals Division Council of ISI.

No handbook of this type can be made complete for all times to come at the very first attempt. During the course of use of this handbook, it should be possible to make suggestions with regard to improving its utility. All such suggestions may be passed on to ISI who will receive them with appreciation and gratitude. These suggestions will be taken into consideration while revising the handbook.

SECTION I

INTRODUCTION

1.1 Scope

This handbook deals with electric metal-arc welding done by hand. It deals in simple language with the various aspects of this process which will be of practical utility to the welder. Some of the common welding terms which a welder is likely to come across are explained in Appendix A. For a complete list of welding terms, he is advised to refer to IS : 812-1957 Glossary of Terms Relating to Welding and Cutting of Metals. The important aspects covered in this handbook are welding equipment, electrodes, safety in welding, welding procedures and techniques. Elements of welding metallurgy have also been explained to assist the welder to adopt suitable welding procedures depending upon the metal to be welded. Methods of inspection and testing of welds and economics of welding have also been included as knowledge of these will assist the welder in producing economical and quality welds.

1.2 Definition

Welding is a method of joining metals. The faces to be joined are heated suitably until they become plastic or liquid. When the faces are rendered plastic, additional pressure is required to complete the joint. This process is popularly known as *forge welding* or *resistance welding*. When the faces to be joined are rendered liquid, pressure is not necessary to complete the joint. This process is called *fusion welding*. In this process sometimes additional metal is added to the joint by melting a metallic rod called filler rod or filler metal.

1.3 Historical Development

The art of joining metals is about 3 000 years old. In India, probably the oldest surviving piece of welding is the Iron Pillar at Delhi which is about 1 500 years old. It was discovered a long time ago that by heating two pieces of metal and then by hammering the heated ends together, the two pieces could be joined together. The Iron Pillar was probably made by this method. This discovery was the forerunner of what is now known as the *forge (or blacksmith) welding*.

The next discovery was that by burning acetylene gas in air or in oxygen, a very hot flame could be obtained and this flame was used for welding of metals. Where acetylene is used as a fuel gas along with oxygen, the process is known as *oxy-acetylene welding*. The edges of the metal pieces to be joined are placed close to each other and melted together so as to form one piece after cooling. Filler metal may be added by using a filler rod to give the required size and shape to the final joint.

In the year 1885, A Russian scientist, M. V. Bernardos, discovered the process of electric-arc welding. The method adopted by Bernardos is illustrated in Fig. 1. The workpiece is connected to the negative pole and the carbon electrode is connected to the positive pole of a direct current circuit. An electric arc is formed between the end of the carbon electrode and the workpiece. The heat of the arc is sufficient to melt the faces of the joint and also the filler rod which is fed into the arc. This forms the basis of what is today known as *carbon-arc welding*.

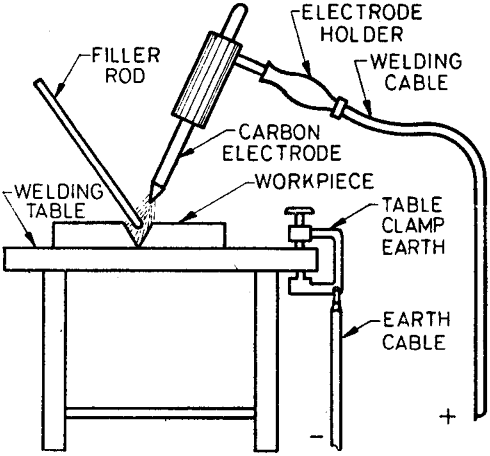


Fig. 1 Bernardos Method of Welding

In 1890, Slavianoff modified Bernardos method by replacing the carbon electrode with a metallic electrode. This method is known today as *metal-arc welding*. In this method, the metallic rod serves both as an electrode for forming the arc and as a filler metal for filling the joint.

This process was further developed by Oscar Kjellberg of Sweden in 1907 by applying a chemical coating called 'flux' on the metallic electrode which had the effect of producing a stable arc and protecting the molten metal passing across the arc. This method is today known as *shielded-arc welding* and is illustrated in detail in Fig. 2.

Many new developments have taken place since then and today most ferrous and non-ferrous metals may be welded by different methods. The chart showing derivation of various welding methods that are commonly in use is given in Fig. 3.

1.4 General Explanation

Practically all electric-arc welding today is done by the shielded-arc welding process. This process is suitable for welding either with an alternating current or with a direct current or with both.

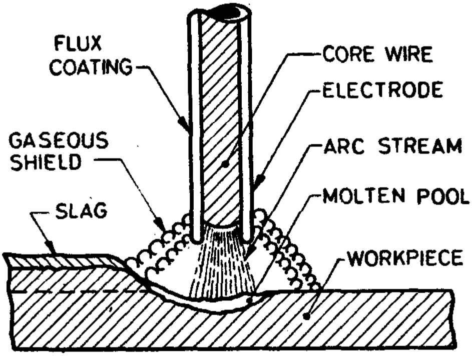


Fig. 2 Diagrammatic Sketch Showing Shielded-Arc Welding

In electric-arc welding, the temperature of the arc is around 6 500°C and when this tremendous heat is concentrated at the point of welding, it melts a small pool of metal in the work. The electrode is also melted by the heat of the arc and deposited into this small pool in a molten state. The molten metal in the pool is agitated by the action of the arc and thus the base or the parent metal is thoroughly mixed and refined with the result that after cooling a sound union is formed.

The steel in its molten state tends to combine with the oxygen and nitrogen of the atmosphere and forms compounds called oxides and nitrides which are dissolved in the steel. These compounds weaken the steel and make it brittle. When bare wire is used as an electrode, the formation of nitrides and oxides is unavoidable. The arc is also not stable. To get sound and ductile weld metal and to get a stable arc, coated electrodes have to be used.

When coated electrodes are used in welding, the flux coating sustains the arc and provides a gas-shield to prevent the oxygen and nitrogen of the atmosphere from combining with the molten metal. Further, the coating melts in the arc and forms a layer of slag over the weld metal and protects it during cooling.

Some of the other types of electric-arc welding are:

a) submerged-arc welding,
b) inert-gas metal-arc welding with non-consumable electrode,
c) inert-gas metal-arc welding with consumable electrode, and
d) carbon dioxide shielded metal-arc welding.

Each of these processes has its definite place in the scheme of welding, depending on the material to be welded.

1.4.1 *Submerged-Arc Welding* — In submerged-arc welding (*see* Fig. 4) which is an automatic or a semi-automatic process, the electrode is a bare

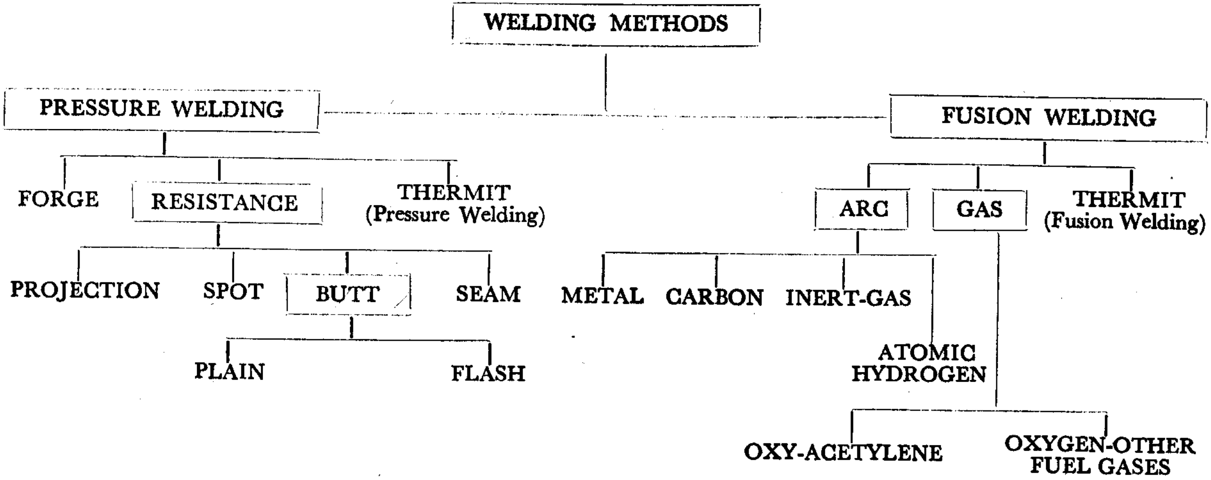


Fig. 3 Chart Showing Welding Methods

wire which is fed into the molten pool through a layer of granular flux which is deposited along the weld seam in front of the electrode. The arc is consequently submerged under the flux and is invisible to the eye. A portion of the flux melts and forms a slag which covers the weld metal. The unfused flux may be reclaimed and re-used.

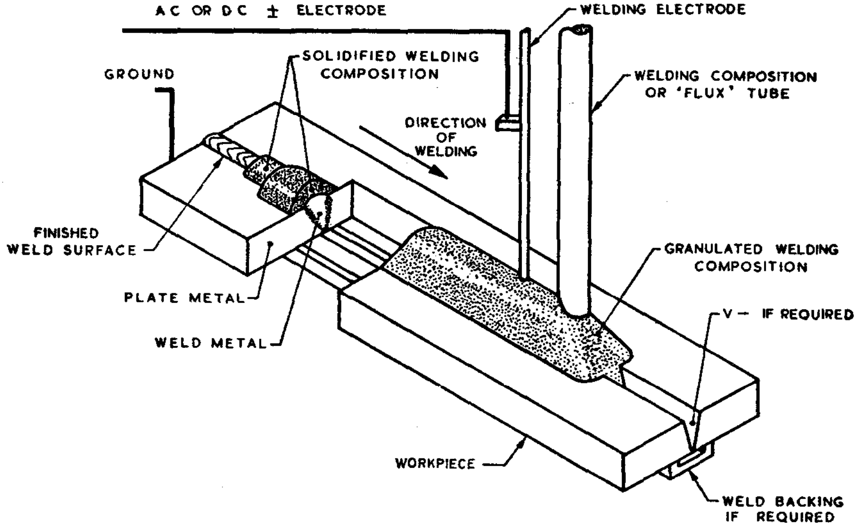


Fig. 4 Submerged-Arc Welding

1.4.2 *Inert-Gas Metal-Arc Welding with Non-consumable Electrode* — This process is mainly used for the welding of aluminium, magnesium and stainless steels and the arc is struck between a tungsten electrode and the workpiece, filler metal being added by hand. The tungsten electrode is not consumed and serves the same purpose as the carbon electrode in carbon-arc welding. The arc is protected from the ill effects of oxygen and nitrogen of the atmosphere by a stream of argon gas which is inert (has no effect on steel) and surrounds the arc completely.

1.4.3 *Inert-Gas Metal-Arc Welding with Consumable Electrode* — This process is a further development of the tungsten electrode process already described, but in this case a bare wire electrode takes the place of the non-consumable tungsten electrode. This wire serves to provide the arc as well as the filler material. The arc is shielded by argon gas. Very high deposition rates and deep penetration are possible with this process and it is, therefore, used for the welding of heavy sections in aluminium, stainless steels, copper, etc.

1.4.4 *Carbon Dioxide Shielded Metal-Arc Welding* — This process is mainly used for the welding of mild steel and low alloy steels. In this case, a bare wire electrode is used and the arc is struck between this electrode and the workpiece. This arc is shielded by carbon dioxide. Higher welding speed, better weld penetration and lower cost are possible with this process. The filler wire has to be of special composition as otherwise the arc becomes rough and considerable spatter occurs.

1.5 Welding Equipment

Suitable welding equipment is necessary for arc welding. This equipment consists of either a transformer to provide alternating current or a generator or a rectifier to provide direct current. This subject is dealt with in detail in Section 2.

SECTION 2

WELDING EQUIPMENT AND ACCESSORIES

2.1 General

The equipment and accessories required for electric-arc welding usually consist of:

a) equipment to provide the welding current,

b) cable to convey the current from the equipment to the electrode holder and to the workpiece,

c) electrode holder to grip the electrode and also to convey the current to the electrode, and

d) accessories which the welder has to use during and after welding.

2.2 Welding Equipment

Arc-welding equipment may be classified into two categories on the basis of the nature of the welding current, namely, those which supply alternating current and those which supply direct current. The theory of AC and DC currents is explained in Appendix B. Both the types of equipment may be designed for use by a single operator or by two or more operators (commonly known as multiple-operator set) (*see* Fig. 5A). These two types of equipment may be either of the stationary or the mobile type.

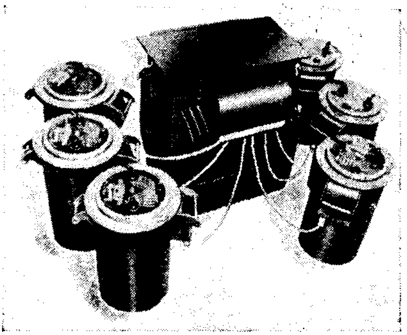


Fig. 5A Multiple-Operator Transformer

2.2.1 *Alternating Current Equipment* — Alternating current for welding is obtained by using a transformer, the primary side of which is connected to the supply mains and the secondary side to an electrode and the workpiece. Usually welding transformers are designed to have an open-circuit voltage between 45 and 100 volts. An open-circuit voltage of 100 volts is used for

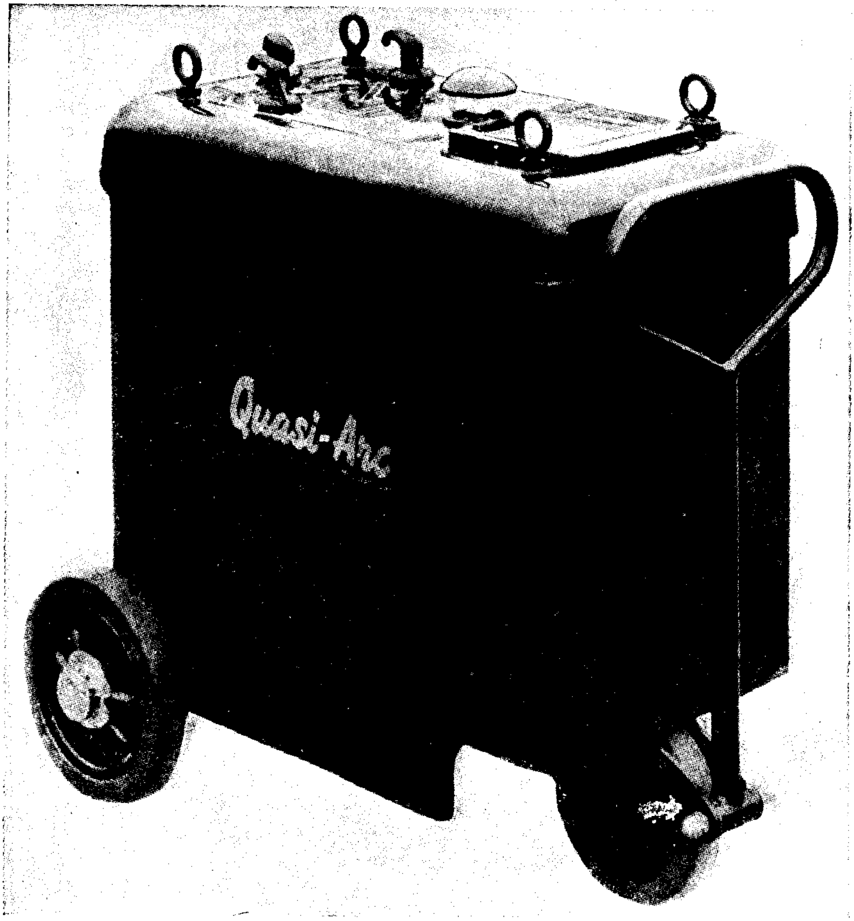


FIG. 5B SINGLE-OPERATOR TRANSFORMER

special applications. Multiple-operator sets (*see* Fig. 5A) usually have an open-circuit voltage of 90 volts. A single-operator set is shown in Fig. 5B.

In transformers, the welding current is controlled by one of the following methods:

a) Moving core method,
b) Moving coil method,
c) Tapped choke method, and
d) Magnetic amplifier method.

A typical circuit of a transformer welding set employing the moving core method of control is illustrated in Fig. 6. The control of the output depends on the amount of the laminated centre core which protrudes into the windings and is usually varied by means of a hand-wheel which is linked to the core.

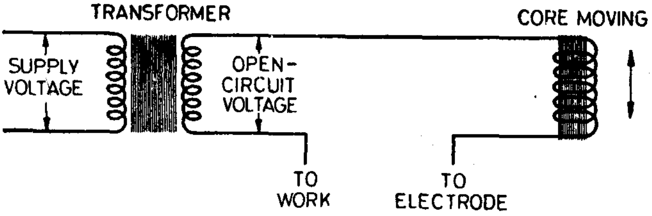


FIG. 6 MOVING CORE METHOD

A typical circuit which has the moving coil type of control is illustrated in Fig. 7. This is similar in principle to the moving core type, except that in this case the coil moves up and down and the core is stationary. This type of equipment is seldom found in practice.

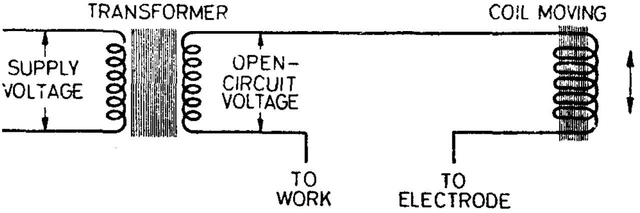


FIG. 7 MOVING COIL METHOD

By far, the best and the most common method of control of the current output is by means of a tapped choke. A typical wiring diagram of this method is shown in Fig. 8. This method does not give stepless control of the current over the whole welding range, but if a sufficient number of tappings is provided, it is possible to control the current to an extent which is acceptable in practice. The value of welding current tapped from the choke decreases as the number of turns left in circuit increases.

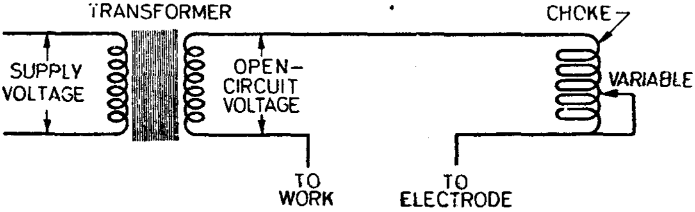


FIG. 8 TAPPED CHOKE METHOD

The fourth and last method of transformer control is by means of a magnetic amplifier. This method requires an external source of direct current of low amperage and voltage, and depends on the fact that if an alternating current is passed through a coil and a direct current is passed through another coil wound on the same core, any increase in the direct current will bring about a corresponding increase in the amount of alternating current allowed to flow in the circuit. This type of control is becoming more popular and gives infinite stepless regulation over the whole welding range. A typical circuit diagram of this method of control is shown in Fig. 9.

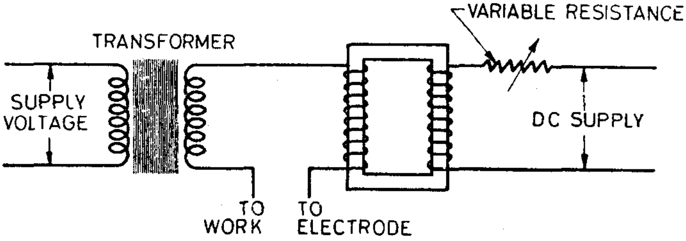


Fig. 9 Magnetic Amplifier Method

2.2.2 *Direct Current Equipment* — Direct current welding equipment may be divided into two types. In one type the direct current required for welding is supplied by a generator which is driven either by a motor or an engine. In the second type (known as a transformer rectifier set), an AC transformer is used and the output is rectified by metal plate rectifiers in the circuit or by valve rectification. With the growing reliability of metal plate rectifiers, this type of rectification is normally used, though sometimes one may come across sets using valve rectification.

It is not intended to deal with the theory of DC generation here, but it is sufficient to state that it is possible to control the output of DC generators in such a way as to give stepless regulation. The open-circuit voltage on the best type of generator may usually be varied between 45 and 80 volts.

The generator is connected to an AC or DC motor which draws its power from the supply mains. Where no electric supply is available, the generator may be connected to a petrol or diesel engine.

2.2.3 *Advantages and Disadvantages of AC and DC Equipment* — From the point of view of welding metals and ease of operation, there is no difference between these two types of currents. The following are the advantages and disadvantages of alternating and direct currents:

AC Equipment

Advantages:

a) Low initial cost, the machine being a simple transformer.

b) Low maintenance cost, as it has no moving parts. No-load losses are very small.

c) Low operating costs.
d) No magnetic arc blow.
e) No change of polarity when working with various types of electrodes.

Disadvantages:

Confined mostly to ferrous metal-arc welding.

DC Equipment

Advantages:

a) Suitable for metal-arc welding of all metals.
b) Produces satisfactory results on thin metals where low currents are used.

Disadvantages:

a) More or less opposite to the advantages of AC.
b) Polarity becomes important with DC when it is realized that approximately 70 percent of the heat of the arc is produced in the positive pole.

2.3 Welding Accessories

Arc-welding accessories consist of cable, cable connector, electrode holder, earth clamp, hand screen, head screen, apron, gloves, chipping hammer and wire brush. It is important that the accessories used by the welder are comfortable and maintained properly since they contribute to a large extent to his efficiency.

2.3.1 *Cable and Cable Connector* — The cable connecting the welding set to the electrode holder is usually called the *welding cable*. The cable connecting the welding set to the workpiece is called the *earthing cable*. These cables should be of single core and tough rubber sheathed (*see* Fig. 10) and should be designed to give maximum flexibility and long service. Depending on the rated current-carrying capacity the cross-sectional area of the cable will vary. The cable should be of sufficient cross-section to allow the current to flow without getting overheated. Cable connectors are used for joining lengths of cable together. The practice of bolting together the ends of cables should be discouraged, as there is a danger of receiving shock from the exposed joint. A typical cable connector is illustrated in Fig. 11.

2.3.2 *Electrode Holder* — There are various designs of electrode holders but there are two main types, namely, the fully insulated type (*see* Fig. 12A) and the partially insulated type (*see* Fig. 12B). Both the types have a handle, jaws to grip the electrode (either using a spring or a screw device) and a means of connecting the cable. Fully insulated holders are useful for welding in confined spaces where there is a danger of the holder touching the workpiece. In the case of partially insulated holders, there is always the danger

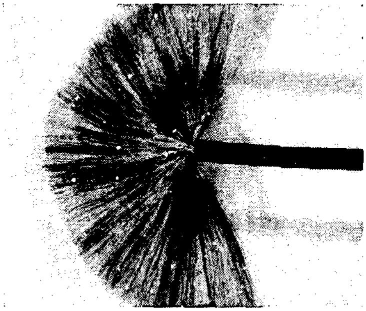


Fig. 10 Cable

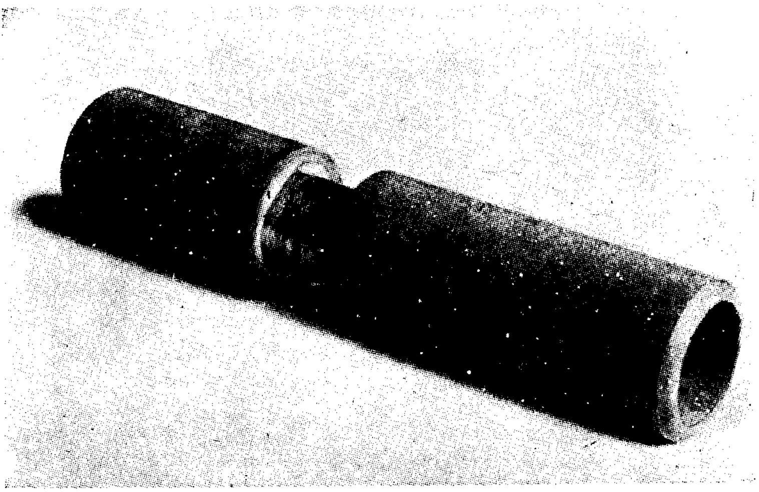


Fig. 11 Cable Connector

of the uninsulated jaw making electrical contact with the workpiece. The jaws are usually made of a hard copper alloy. When the holder is not in use, it should be placed on a piece of wood or hung on an insulated hook.

2.3.3 *Earth Clamp* — Earth clamps which are sometime called 'Return Current Clamps' are used for fixing the earthing cable to the workpiece or to the welder's bench. They should have a proper grip to ensure good electrical contact (*see* Fig. 13).

2.3.4 *Hand Screen (Shield) and Helmet (Head Screen)* — These are appliances intended for the protection of the operator's eyes and face. A hand screen

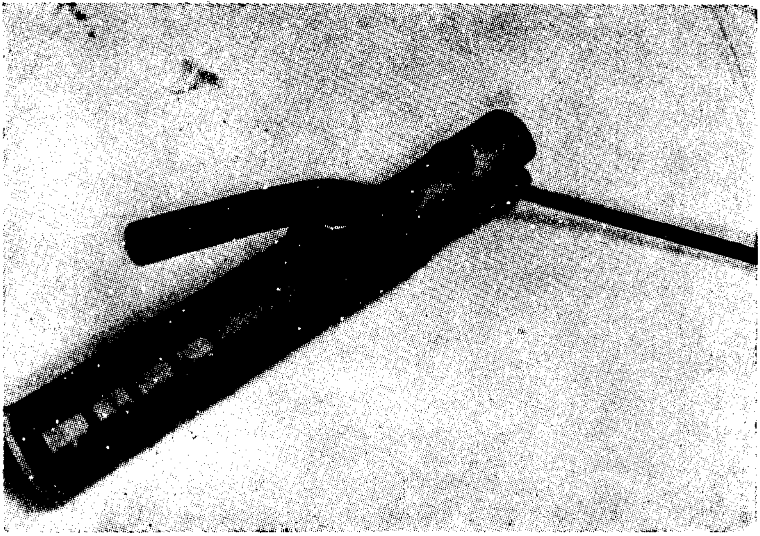


FIG. 12A FULLY INSULATED ELECTRODE HOLDER

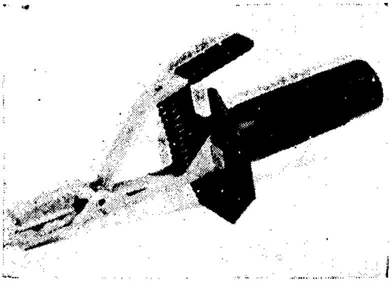


FIG. 12B PARTIALLY INSULATED ELECTRODE HOLDER

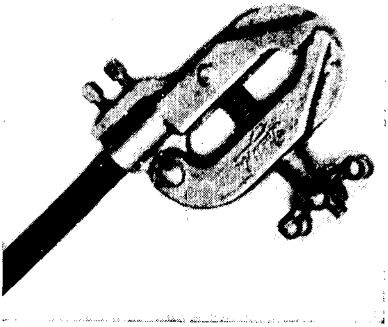


FIG. 13 EARTH CLAMP

(*see* Fig. 14) is held in the hand, whereas a head screen (*see* Fig. 15) is worn on the head and kept in position usually by a band passing round the back of the head. They are fitted with specially designed dark glasses through which the operator is able to look at the arc without damaging his eyes. This type of glass is expensive and is usually protected from spatter by the provision of a plain glass on each side. The plain glass will have to be renewed from time to time.

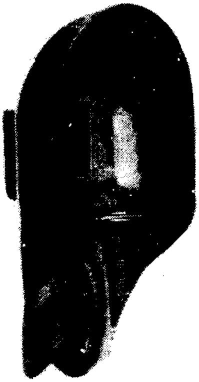


FIG. 14 HAND SCREEN (SHIELD)

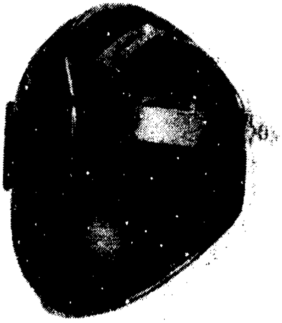


FIG. 15 HELMET (HEAD SCREEN)

2.3.5 *Apron* — An apron is intended for the protection of the operator's clothes from the sparks and heat of the arc. It is usually made of heat-resistant chrome leather and is tied round the waist and the neck (*see* Fig. 16). In overhead welding, leggings and a skull cap of chrome leather are also used.

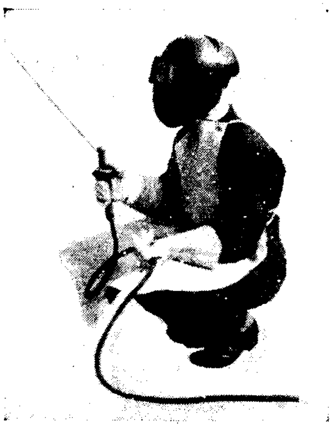


FIG. 16 GLOVES AND APRON

2.3.6 *Gloves* — Gloves are intended for the protection of hand and forearm from the heat and spatter of the arc. They are usually made of chrome leather (*see* Fig. 16).

2.3.7 *Chipping Hammer* — A chipping hammer (*see* Fig. 17) is used for removing the slag from the weld.

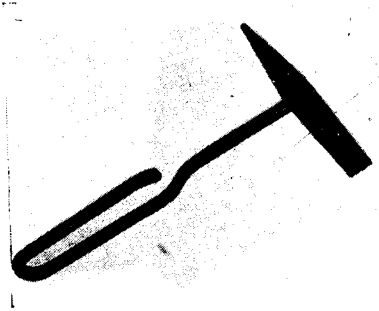


FIG. 17 CHIPPING HAMMER

2.3.8 *Wire Brush* — Wire brush is used for cleaning the weld (*see* Fig. 18).

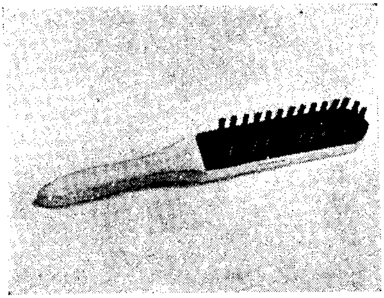


FIG. 18 WIRE BRUSH

SECTION 3

WELDING TOOLS AND GAUGES

3.1 General

In Section 2, welding equipment and accessories have been described. This chapter deals with a few important tools and gauges which a welder may be called upon to use in fitting up joints and measuring joints and welds.

3.2 Welding Tools

The important tools required by the welder are described in **3.2.1** to **3.2.12**.

3.2.1 *Scriber* — This is made of hardened steel or brass and is used for marking lines on the job (*see* Fig. 19).

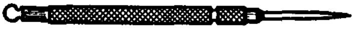


Fig. 19 Scriber

3.2.2 *Centre Punch* — This is normally used for marking the centres of holes on the job and to make a series of marks indicating the line along which gas cutting has to be done (*see* Fig. 20). It is used in conjunction with a scriber or scriber compass.

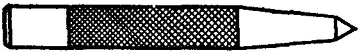


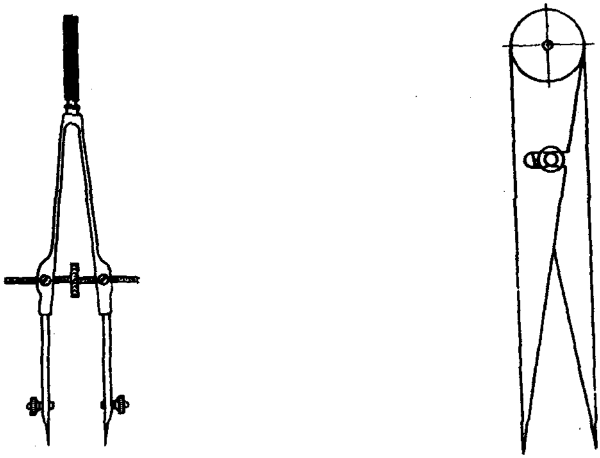
Fig. 20 Centre Punch

3.2.3 *Scriber Compass* — This is used for marking circles on the job and also to divide measurements (*see* Fig. 21).

3.2.4 *Steel Square* — A steel square is used to draw lines at right angles to each other. It is also used to set surfaces perpendicular to each other and to test their trueness.

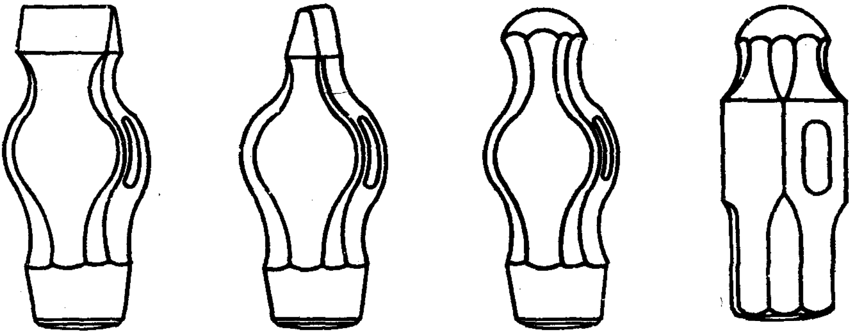
3.2.5 *Hammer* — Different types and weights of hammers made of cast steel with their faces hardened and tempered are commonly used for chipping metal, for making marks with a punch, etc. The common types are indicated in Fig. 22.

3.2.6 *Engineer's Vice* — The engineer's vice (*see* Fig. 23) is made of cast iron or steel and is identified by its weight or length of jaws. It is used for holding the workpiece tightly in a required position. The workpiece should always be held in the centre of the jaws as far as possible. In order to prevent the vice from marking the workpiece in the case of soft metals, aluminium or fibre inserts may be used.



21A Spring Bow Divider Compass **21B Lock Joint Compass**

FIG. 21 SCRIBER COMPASSES



22A Straight Pein **22B Cross Pein** **22C Ball Pein** **22D Ball Pein Sledge**

FIG. 22 HAMMERS

3.2.7 *Chisels* — Chisels used by welders are generally of three types, namely, flat, cross-cut and half-round nose (*see* Fig. 24). They are made of cast steel, hardened and tempered. The cutting angles are usually between 60° and 70°. A flat chisel should be ground with the cutting edge slightly convex, thus preventing the edges from dragging the material when being cut. A cross-cut chisel is normally used for cutting keyways and a round-nose chisel is used for oil grooves.

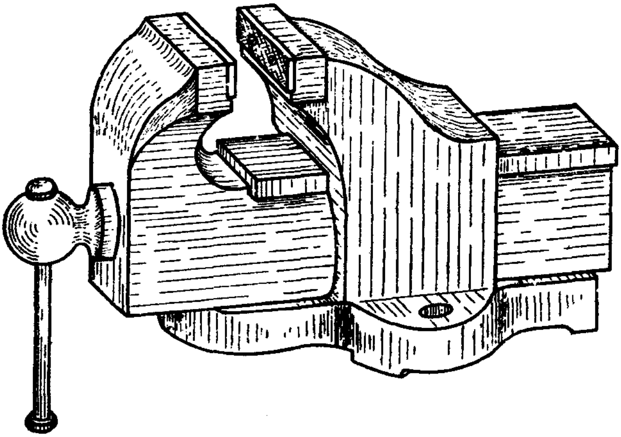


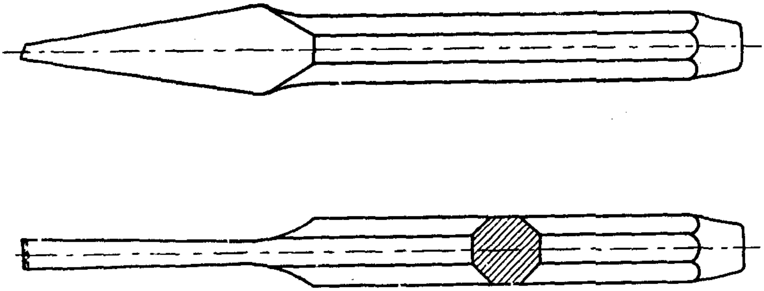
FIG. 23 ENGINEER'S VICE

3.2.8 *Files* — A file is a tool with its surface covered with sharp-edged furrows or teeth and is used for removing metal from other surfaces. These are made in different shapes and sizes (*see* Fig. 25). Broadly, these may be classified in two ways, according to the cross-section and according to the spacing of the teeth.

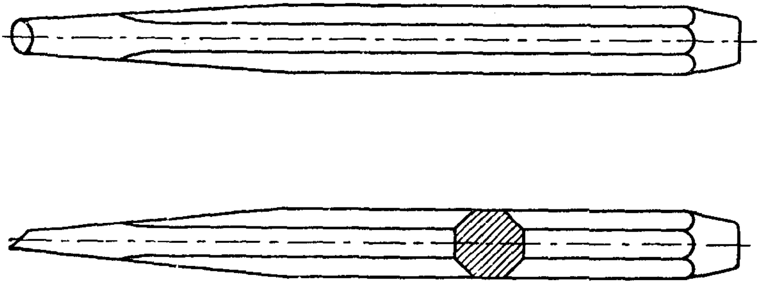
According to the first classification, the principal varieties are flat, hand, half-round, round, square, three-square and knife-edge, and according to the second, the different varieties are bastard, second cut, smooth and dead smooth.

Files are either single cut or double cut. In the single cut files, the parallel rows of teeth are inclined at an angle of 65° to 85° to the axis of the file. The double cut files have two series of teeth, crossing each other, the first series is inclined at an angle of 40° to 45° and the second series at an angle of 70° to 80° to the axis of the file. The length of the file is measured from the shoulder to the point, that is, from the root of the tapered portion which fits into the wooden handle to the end of the blade.

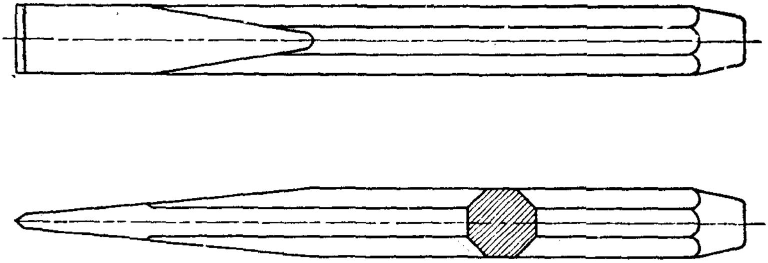
3.2.9 *Hack-Saw* — A hack-saw is used for hand-cutting of metals. The frame is made of mild steel to which blades of hardened steel may be fitted (*see* Fig. 26). Hack-saws are available in standard lengths of 200 mm, 250 mm, and 300 mm. Fine blades having 22 to 32 teeth per 25 mm are used for cutting sheet metal and hard materials. Coarse blades of 14 to 18 teeth per 25 mm are used generally on thicker material. As the cut is made on the forward stroke, the blade should be fitted with the teeth facing forward.



24A Cross-Cut

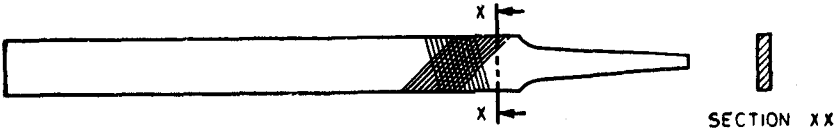


24B Round Nose

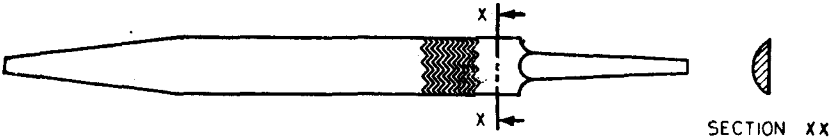


24C Flat

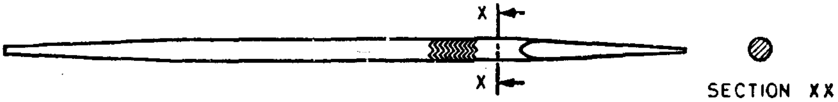
FIG. 24 CHISELS



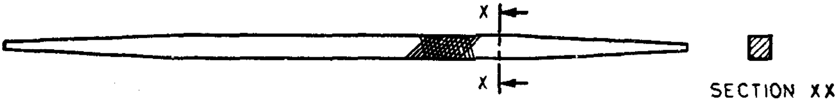
25A Flat File



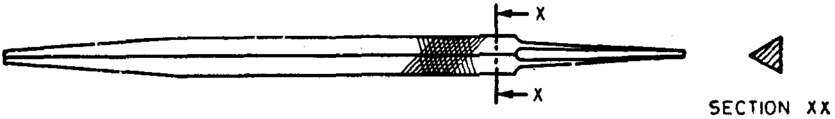
25B Half-Round File



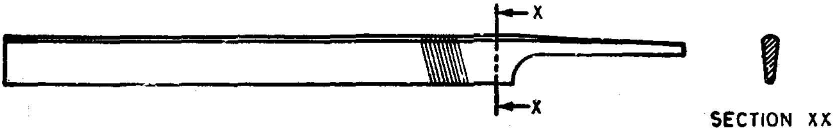
25C Round File



25D Square File



25E Three-Square File



25F Knife-Edge File

Fig. 25 Files

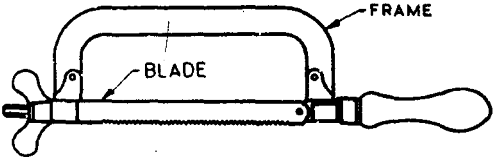


FIG. 26 HACK-SAW

3.2.10 *V-block* — A V-block is used for aligning the workpiece before welding and to keep it in level (*see* Fig. 27).

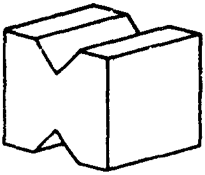


FIG. 27 V-BLOCK

3.2.11 *Clamp* — A clamp is used for holding a workpiece in position so that it may be welded easily (*see* Fig. 28).

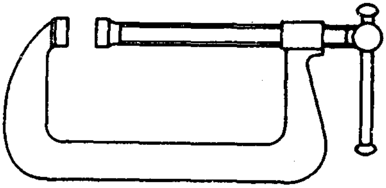


FIG. 28 CLAMP

3.2.12 *Tongs* — Tongs are used for handling a hot workpiece (*see* Fig. 29).

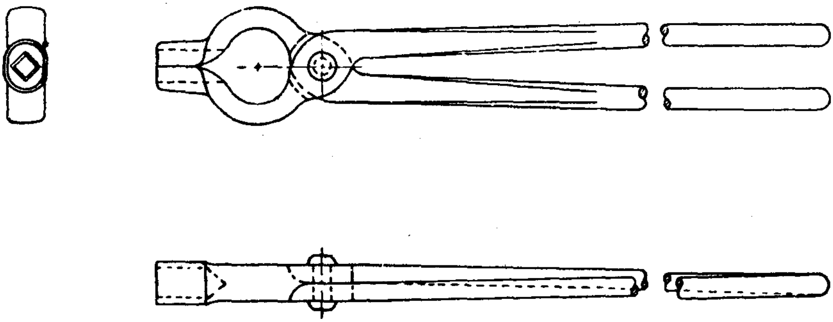


FIG. 29 SMITH'S TONGS

3.3 Gauges

The important gauges frequently used by the welder are described in **3.3.1** to **3.3.3**.

3.3.1 *Steel Rule* — The steel rule is commonly used by welders for measuring the thickness of plates and for marking dimensions on the workpiece in accordance with the drawings furnished. The steel rule is of rectangular cross-section and of a length varying from 15 to 100 cm. The rules are provided with graduations in millimetres.

3.3.2 *Calipers* — Calipers are used for measuring the distances between or over surfaces, particularly the inside and outside diameters and for comparing the dimensions of workpiece with such standards as steel rules and plug gauges. There are two main types, namely, firm-joint calipers and spring calipers with adjusting screws (*see* Fig. 30).

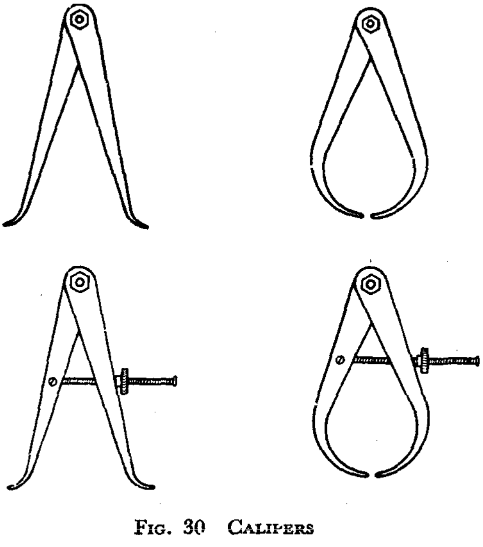
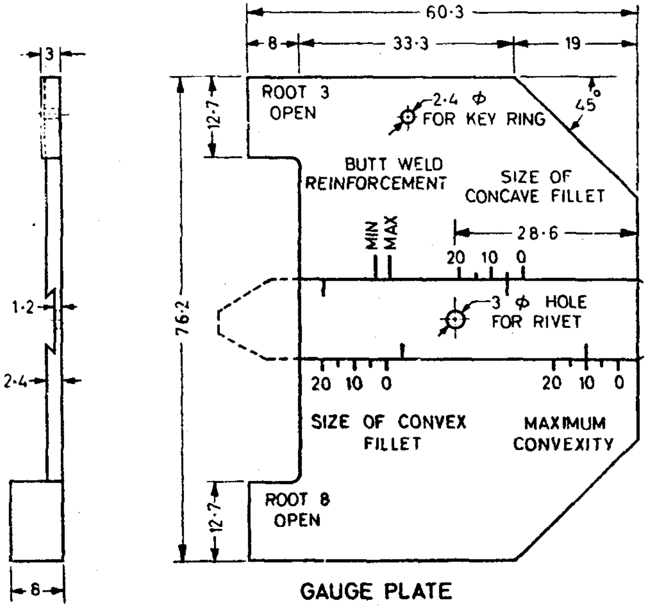
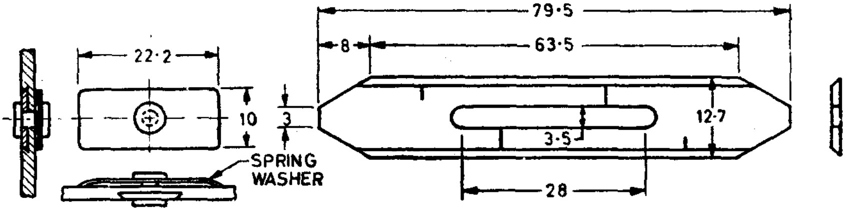


FIG. 30 CALIPERS

3.3.3 *Weld Gauge* — This is a gauge used for determining the size, the amount of convexity and the reinforcement of a weld. It is made of steel or any other metal. Weld gauges are of different forms. A typical weld gauge along with its method of use is illustrated in Fig. 31. A few other types of weld gauges together with the methods of using them are illustrated in Fig. 32.



GAUGE PLATE



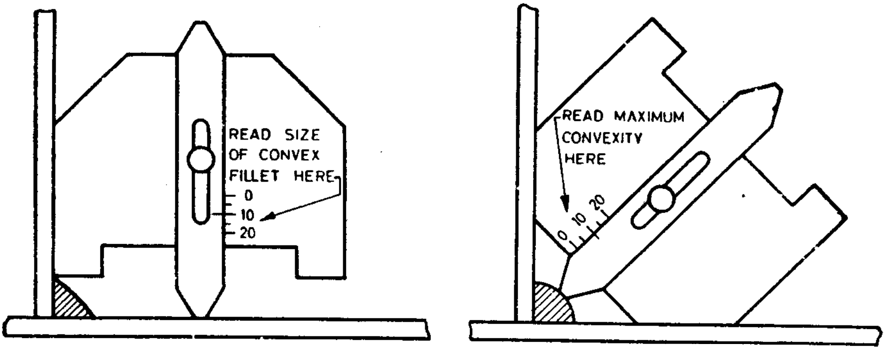
POINTER

All dimensions in millimetres.

NOTE — This gauge is not suitable for measuring fillet weld when the parts are joined at an acute angle.

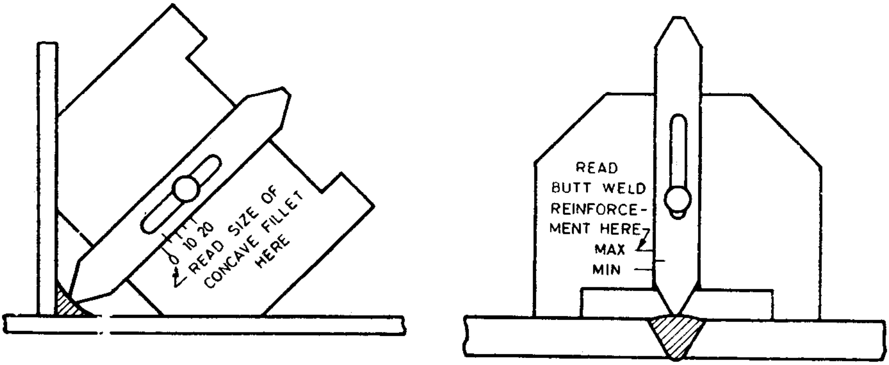
31A Typical Weld Gauge

FIG. 31 TYPICAL WELD GAUGE AND ITS METHOD OF USE (*Continued*)



TO MEASURE THE SIZE OF A CONVEX FILLET WELD

TO CHECK THE MAXIMUM PERMISSIBLE CONVEXITY

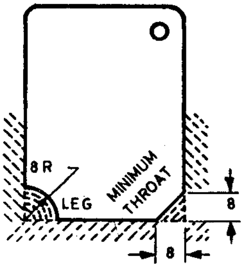


TO DETERMINE THE SIZE OF A CONCAVE FILLET

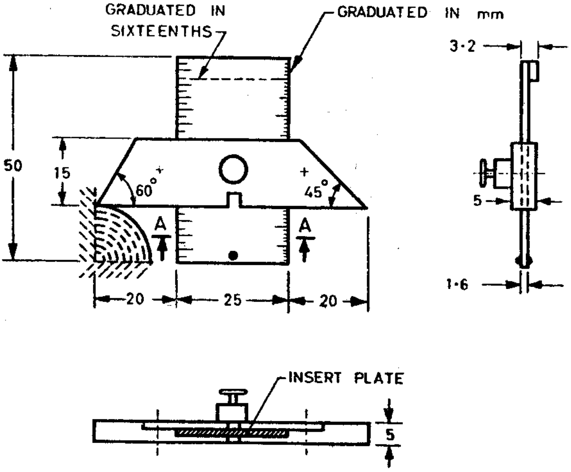
CHECKING BUTT WELD FOR MAXIMUM AND MINIMUM CONVEXITY

31B Method of Using Weld Gauge

FIG. 31 TYPICAL WELD GAUGE AND ITS METHOD OF USE



32A Fillet Gauge

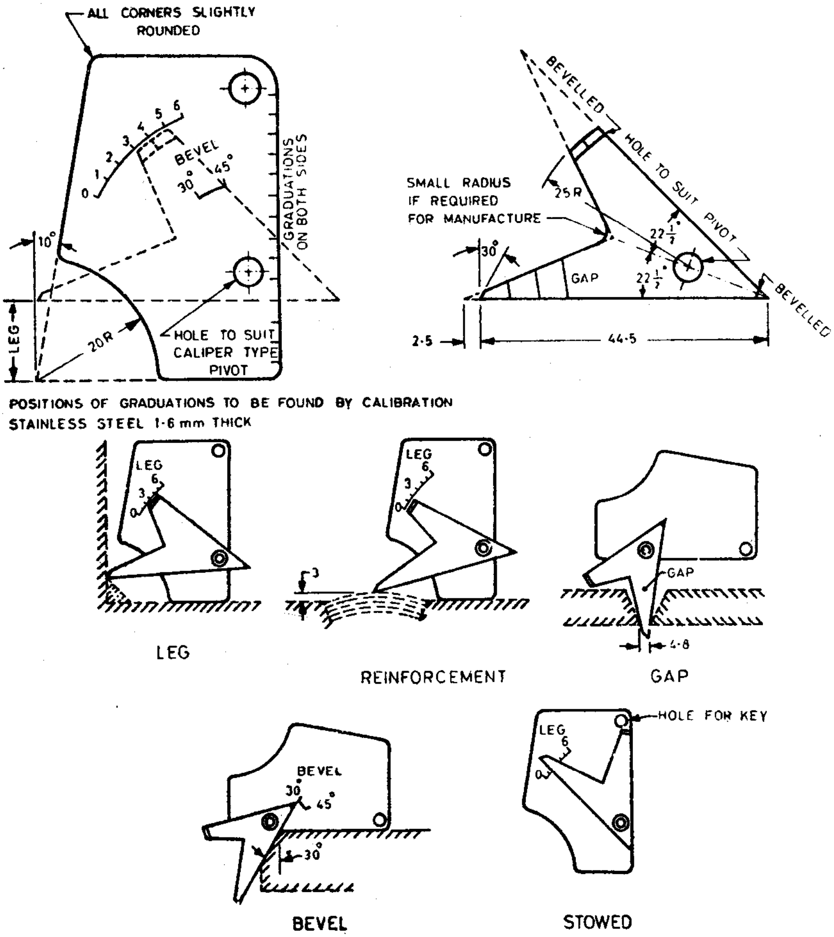


SECTION AA

32B Alternative Fillet Gauge

All dimensions in millimetres.

FIG. 32 OTHER TYPES OF WELD GAUGES (*Continued*)


ALL CORNERS SLIGHTLY ROUNDED
0
1
2
3
4
5
6
BEVEL
30°
45°
GRADUATIONS ON BOTH SIDES
10°
LEG
20R
HOLE TO SUIT CALIPER TYPE PIVOT
BEVELLED
HOLE TO SUIT PIVOT
SMALL RADIUS IF REQUIRED FOR MANUFACTURE
25R
30°
GAP
22½°
22½°
BEVELLED
2·5
44·5
LEG
6
3
0
3
4·8
GAP
HOLE FOR KEY
30°

POSITIONS OF GRADUATIONS TO BE FOUND BY CALIBRATION

STAINLESS STEEL 1·6 mm THICK

LEG

REINFORCEMENT

GAP

BEVEL

STOWED

32C Another Typical Weld Gauge

All dimensions in millimetres.

Fig. 32 Other Types of Weld Gauges

SECTION 4

ARC WELDING ELECTRODES

4.1 Manufacture

An electrode consists of a metallic wire called 'core wire' which is coated uniformly with flux. The core wire is usually received from the rolling mill in large coils. It is cleaned and straightened. The flux coating is then applied on the core wire either by dipping or by extrusion. In the former process, the straightened wire is cut into standard lengths and then dipped into a container carrying flux paste. In this case, it is not possible to control closely the uniformity and the thickness of coating and the rate of production is also low. In the extrusion process, the straightened wire is fed into an extrusion press where the coating is applied under pressure. The wire may be fed in one continuous length in which case it is cut into standard lengths of electrodes after coating. Alternatively, the wire may be cut into standard lengths and then coated by this process.

Sometimes a fabric or asbestos sleeve impregnated with flux material is wrapped on to the core wire. In certain electrodes, called tubular electrodes, a metallic tube is filled with metal and alloy powders and arc stabilizers and sealed at both ends. Some hardfacing electrodes are made in this way.

Electrodes are thoroughly dried or baked after production because moisture causes an unstable arc, heavy spatter and porosity in the weld metal.

4.2 Flux Covering (Coating)

Electrodes may be light-coated, medium-coated and heavy-coated. Light-coated electrodes have a fair amount of flux coating, the slag from which will fully cover the weld bead during welding. The ratio of coating diameter to the core wire diameter, called coating factor, is generally between 1·25 and 1·3 for a light-coated electrode. Medium-coated electrodes have a coating factor of about 1·4 to 1·5 while heavy-coated ones have a coating factor anywhere between 1·6 to 2·2.

Heavy-coated electrodes have a tendency to form a sleeve or a cup at the arc end because the core wire is burning ahead of the coating. This sleeve helps to direct and concentrate the heat of the arc, giving greater depth of fusion at the joint. It also increases the temperature of the electrode tip. The slag from heavy-coated electrodes is very thick and is usually self-detaching.

Heavy-coated electrodes are, however, difficult to use in vertical and overhead positions. For these difficult positions, light-coated and medium-coated electrodes are best suited. Light-coated electrodes giving a heavily shielded arc are popular among welders for vertical and overhead welding as there is less slag to be controlled.

4.2.1 *Functions of Flux Covering (Coating)* — The functions which the flux coating performs and the materials which assist in performing each of these functions are as follows:

a) It helps to strike and maintain the arc. The materials which help this function are called *arc stabilizers*. They generally consist of titanium dioxide, calcium carbonate and potassium compounds.

b) It helps to produce a protective gaseous shield around the arc. The materials which perform this function are called *gas-shielding materials*. They consist of starch, wood flour and carbonates, which produce carbon dioxide, carbon monoxide and hydrogen around the arc.

c) It helps to produce a slag which protects the metal from attack by oxygen and nitrogen of air during passage across the arc and also forms a layer over the weld bead. The materials which perform this function are called *slag producers*. They consist of iron oxide, manganese dioxide, china clay, mica and other silicates.

d) It helps to deoxidize and refine the weld metal. The materials which perform this function are called *deoxidizers*. The well-known deoxidizers are ferro-silicon, ferro-titanium and ferro-manganese.

e) It helps to modify and control the strength of the weld metal. The materials which perform this function are called *alloying compounds*. The commonly used ferro-alloys are ferro-manganese and ferro-molybdenum.

f) It helps to form a sleeve at the burning end of the electrode and to concentrate welding heat. This is made possible by having a thick coating which melts a little more slowly than the wire.

g) It helps to make vertical and overhead welding easy for the welder. This is controlled by making the slag quick-freezing, that is, it will re-solidify immediately and prevent the liquid metal from falling.

h) It helps to insulate the electrode so that it may be used at higher current as compared to bare wire without getting red hot.

j) It helps to prevent spatter and gives a smooth and rounded appearance to the weld bead.

4.2.2 *Types of Flux Covering (Coating)* — The flux coatings are normally divided into seven types based on their chemical composition. The characteristics of each of these types are given below:

a) *Type* 1 — This type of covering (coating) contains at least 15 percent of cellulosic material. This class of electrode is characterized by a deeply penetrating arc and rapid burn-off rate. Spatter loss is somewhat high and the weld finish is coarser than usual. The deposit has a thin cover of slag which is fairly easy to remove.

Electrodes of this type are of particular value for jobs involving changes in position during welding, for example, in pipe welding, ship-building, etc, and where accurate fit-up of the joint is required. Generally, this class of electrode is suitable for use with DC positive but some types are available for use with AC where a high open-circuit voltage is available.

b) *Type* 2 — Electrodes of this type of covering (coating) cover most of the popular brands of all-position and general purpose electrodes. They produce little spatter and the weld finish is good.

c) *Type* 3 — This type of covering (coating) yields a much more fluid slag than that produced by electrodes of type 2 covering and though suitable for welding in all positions, welding in the overhead and vertical upwards position is far easier with this class of electrode. The slag is generally easy to detach and the electrode has smooth arc characteristics.

d) *Type* 4 — An electrode with this type of covering (coating) is usually produced with very thick coating and is used for welding in the flat position only. The weld finish is smooth, ripples being less pronounced than on deposits produced by the other classes of electrodes. The principal application is for deep groove welding in thick plates especially where such welds are subject to strict radiographic tests.

e) *Type* 5 — Electrodes of this type are used principally for single run fillet welds where appearance is of primary importance. The degree of penetration is low but the electrodes may be used with the coating touching the work, commonly known as 'touch welding technique'.

f) *Type* 6 — Electrodes of this type are known as low-hydrogen electrodes but are also sometimes referred to as 'Lime Ferritic', 'Lime Fluorspar', 'Ferritic' or 'Basic' type. The weld metal has a high resistance to hot and cold cracking and is less sensitive to variation in plate quality than that of other electrode types. The electrodes are particularly suitable for welding high tensile structural steels where the highest physical properties are required. They are also used for welding steels having higher carbon and sulphur contents than found in normal structural steels and for welding steels of unknown composition.

During manufacture, these electrodes are baked at a high temperature and to obtain the best result they should be properly stored in their original containers and, if necessary, thoroughly dried before use to remove any moisture pick-up. When using these electrodes for welding it is necessary to use a short arc to achieve maximum soundness in the weld deposit.

g) *Type* 7 — Electrodes of this type cover those not classified by the other types and include the latest electrodes which have a percentage of iron powder in their coating giving high metal deposition rate.

4.3 Sizes

Electrodes are usually produced in lengths of 450 mm, 350 mm, 300 mm and 250 mm. About 20 mm is left bare at one end (this is called the contact end) for inserting it into the electrode holder and to provide passage of electric current since the flux coating will not allow current to pass through it. The size of the electrode is measured and designated by the diameter of the core wire. This diameter ranges from 1·6 mm to 9 mm. In the British system, the electrode size is specified in terms of 'gauge', that is, the Standard Wire Gauge (SWG), while in the American system it is specified as fraction of an inch, for example, 1/8 in., 5/32 in., 1/16 in., etc. On the continent and in India now, electrode sizes are specified in millimetres (mm). The corresponding sizes in these systems are given in Table I.

TABLE I CORRESPONDING SIZES OF ELECTRODES IN INDIAN, CONTINENTAL, BRITISH AND AMERICAN SYSTEMS

Indian and Continental System (in mm)	9	8	7	6	5	4	3·2	2·5	2	1·6
British System (in SWG)	*3/8 in.	*5/16 in.	*1/4 in.	4	6	8	10	12	14	16
American System (in fractions of an inch)	3/8	5/16	1/4	7/32	3/16	5/32	1/8	3/32	5/64	1/16

*SWG scale does not provide for diameters of 1/4 in. and above. So fractions of an inch are used.

It should be noted that the corresponding sizes given in Table I are not exact equivalents. For example, 4 SWG is equal to 0·232 in., while the corresponding size 7/32 in. is equal to 0·219 in., and 6 mm is equal to 0·236 in. Thus 4-SWG electrode has a slightly thicker core wire than 7/32 in. electrode, while a 6-mm electrode has a slightly thicker core wire than 4-SWG electrode. But, for practical purposes, these differences do not matter.

The length of an electrode is chosen by the manufacturer according to the convenience of the welder. A 9-mm electrode may be made of short length, say 350 mm, because of its heavy weight. Electrodes of sizes from 3·2 to 6 mm are usually made in 450-mm length as this is the maximum length of an electrode which a welder may use with ease. Some of these may be made in 350-mm length either for the sake of providing access in confined work or for working at the maximum current value. Smaller diameter electrodes, are manufactured in shorter lengths as they get easily bent and twisted and become hot very quickly during welding. A 1·6-mm electrode may be 250 mm long, a 2-mm electrode 300 mm long, and a 2·5-mm electrode 350 mm long.

Stainless steel electrodes have to be shorter than mild steel electrodes because they get hot very quickly. Electrodes containing large amounts of metal and alloy powders in the coating are made shorter in length to prevent loss of these precious compounds in the arc atmosphere due to overheating of the electrode.

Every electrode manufacturer fixes his own lengths for different types and sizes of electrodes. The manufacturer gives full particulars about these in his specification leaflets. Manufacturers are generally reluctant to depart from these lengths because electrodes are produced on mass scale and departure from their normal practice causes delay and loss in production.

4.4 Classification and Coding of Mild Steel and Low Alloy High-Tensile Steel Electrodes

Mild steel and low alloy high-tensile steel electrodes are classified into seven recognized groups, depending upon the chemical composition of the flux coating and performance requirements, such as, welding current conditions, arc and slag characteristics and weld metal quality.

For convenience of reference, the electrodes are given a code number with the help of which it is possible to identify the type of electrode, the welding position in which it may be used under different current conditions, and the weld metal strength that may be allowed.

In India, the following three systems of classification and coding of electrodes are predominant:

a) *Indian System* as laid down in IS : 815-1956 Classification and Coding of Covered Electrodes for Metal Arc Welding of Mild Steel and Low Alloy High-Tensile Steels.

b) *British System* as laid down in B.S. 1719 : 1951 Classification of Covered Electrodes for the Metal-Arc Welding of Mild Steel and of Medium-High-Tensile Steels of Welding Quality.

c) *American System* as laid down in ASTM Designation A 233-58T Tentative Specification for Mild Steel Arc-Welding Electrodes.

A brief outline of each of these systems is described in **4.4.1** to **4.4.3**.

4.4.1 *Indian System of Classification and Coding of Covered Electrodes for Welding Mild Steel and Low Alloy Steels* — In the Indian system the code number consists of the prefix letter *M* to indicate the suitability of the electrode for metal-arc welding of mild steel and of low alloy high-tensile steels of welding quality. This is followed by six digits, of which

a) the *first* digit indicates the type of covering,

b) the *second* digit indicates the welding position or positions in which the electrode may be used,

c) the *third* digit indicates recommended welding current conditions,

d) the *fourth* digit indicates the minimum tensile strength of weld metal,

e) the *fifth* digit indicates the minimum percentage elongation of weld metal in a tensile test, and

f) the *sixth* digit indicates the minimum impact test value of the weld metal.

In addition, there may be a suffix letter *P* to indicate that the electrode is suitable for deep penetration welding, or a suffix letter *A* to indicate that the electrode is suitable for automatic welding.

The symbols used in each of the cases mentioned above are further amplified below:

a) *Type of covering* — The first digit of the code indicates the type of covering as follows:

Digit	*Type of Covering*
1	Having a high cellulose content
2	Having a high content of titania and producing a fairly viscous slag
3	Containing an appreciable amount of titania and producing a fluid slag
4	Having a high content of oxides and/or silicates of iron and manganese and producing an inflated slag
5	Having a high content of iron oxides and/or silicates and producing a heavy solid slag
6	Having a high content of calcium carbonate and fluoride
7	Having a high content of iron powder
9	A covering of any other type not classified above

NOTE — The important characteristics of electrodes, having each of the seven types of coverings are described in Appendix A of IS : 815-1956 Classification and Coding of Covered Electrodes for Metal Arc Welding of Mild Steel and Low Alloy High-Tensile Steels.

b) *Welding positions* (*see Section* 5) — The second digit of the code number indicates the welding position or positions, in which the electrode may be used, as follows:

Digit	*Welding Positions*
1	Flat, inclined, horizontal-vertical, vertical, overhead
2	Flat, horizontal-vertical

Digit	*Welding Positions*
3	Flat
4	Flat, inclined, horizontal-vertical
5	Flat, horizontal-vertical, vertical, overhead
6	Vertical, overhead
9	Any other welding position not classified above

Where an electrode is coded as suitable for vertical and overhead positions, it should be understood that sizes larger than 5 mm are not normally used for welding in these positions. Where an electrode is coded as suitable for welding in the inclined position or the vertical position or in both the positions, it is assumed that this coding implies suitability for welding *in the upward direction* only, unless the description on the electrode label specifies otherwise.

c) *Welding current conditions* — The third digit of the code number indicates the welding current condition recommended by the manufacturer of the electrode, as follows:

Digit	*Welding Current Condition*	*Explanation*
0	D+	Indicates that the electrode may be used on DC with electrode connected to the positive pole
1	$D+A_{95}$	Indicates that the electrode may be used on DC with positive pole and on AC with an open-circuit voltage of over 95 volts
2	$D-A_{70}$	Indicates that the electrodes may be used on DC with the electrode connected to the negative pole and on AC with an open-circuit voltage of over 70 volts
3	$D-A_{45}$	Indicates that the electrode may be used on DC with the electrode connected to the negative pole and on AC with an open-circuit voltage of over 45 volts
4	$D+A_{70}$	Indicates that the electrode may be used on DC with the electrode connected to the positive pole and on AC with an open-circuit voltage of over 70 volts

Digit	*Welding Current Condition*	*Explanation*
5	$D \pm A_{95}$	Indicates that the electrodes may be used on DC with the electrode connected either to the positive or negative pole and on AC with an open-circuit voltage of over 95 volts
6	$D \pm A_{70}$	Indicates that the electrode may be used on DC with the electrode connected either to the positive or the negative pole and on AC with an open-circuit voltage of over 70 volts
7	$D \pm A_{45}$	Indicates that the electrode may be used on DC with electrode connected either to the positive or the negative pole and on AC with an open-circuit voltage of over 45 volts
9	Any other current condition not classified above	Not classified above

d) *Tensile strength of deposited metal* — The fourth digit of the code number indicates the ultimate tensile strength of deposited metal as follows:

Digit	*Minimum Tensile Strength* kg/mm²
1	31·0
2	41·0
3	44·0
4	48·0
5	52·0
6	56·0
7	60·0
8	67·0
9	Any other minimum tensile strength value not classified above

The test for the determination of the ultimate tensile strength of the deposited metal has been prescribed in Appendix B of IS: 814-1963 Specification for Covered Electrodes for Metal Arc Welding of Mild Steel (*Revised*).

e) *Percentage elongation of deposited metal in tensile test* — The fifth digit of the code number indicates the minimum percentage elongation of deposited metal in tensile test as follows:

Digit	*Elongation, Percent, Min*
1	14
2	18
3	22
4	26
5	30
9	Any other elongation not classified above

The test for the determination of the percentage elongation of the deposited metal in tensile test has been prescribed in Appendix B of IS : 814-1963 Specification for Covered Electrodes for Metal Arc Welding of Mild Steel (*Revised*).

f) *Impact test value of deposited metal* — The sixth digit of the code number indicates the minimum impact test value of deposited metal as given below:

Digit	*Impact Strength, Min* kgf·m
1	4·10
2	5·70
3	7·00
4	8·90
5	10·40
9	Any other impact test value not classified above

The test for the determination of impact test value of deposited metal has been prescribed in Appendix B of IS : 814-1963.

4.4.1.1 *Deep penetration electrodes* — In the coding for an electrode, the suffix letter 'P' is used if the electrode has been manufactured to comply with the test requirements and penetration requirements for deep penetration electrodes as specified in IS : 814-1963.

An electrode coded as a deep penetration electrode implies that the electrode is suitable for deep penetration butt welding in the flat position and for deep penetration fillet welding in the flat and horizontal-vertical positions.

Such an electrode is also expected to be suitable for normal penetration welding in the flat and horizontal-vertical positions. If the coding for such an electrode shows that it is suitable for positions other than flat and horizontal-vertical, then it implies that the electrode is suitable for such other positions for normal penetration welding only.

4.4.1.2 *Marking* — Normally each packet of electrodes bears a marking which indicates the classification and coding of the electrodes it contains. This marking is usually in one of the two forms shown in Fig. 33.

IS : 815-1956 Coding		
Specification	Positions	Current Conditions

IS : 815-1956 Coding	
Specification	
Positions	
Current Conditions	

FIG. 33 STANDARD FORMS OF CODING LABEL

Examples of completed coding labels are shown in Fig. 34.

IS : 815-1956 Coding		**M 325241 P**
Specification	Positions	Current Conditions
Ref IS : 814-1963	**F, H**	$\mathbf{D \pm A_{95}}$

IS : 815-1956 Coding	**M 325241 P**
Specification	**Ref IS : 814-1963**
Positions	**F, H**
Current Conditions	$\mathbf{D \pm A_{95}}$

FIG. 34 EXAMPLES OF COMPLETED CODING LABELS

The explanation of the coding illustrated in Fig. 34 is as follows:

a) The electrode is suitable for metal arc welding of mild steel.

b) The electrode covering contains an appreciable amount of titania and produces a fluid slag.

c) The electrode is suitable for welding in the flat and horizontal-vertical positions and satisfies the test requirements of IS : 814-1963 Specification for Covered Electrodes for Metal Arc Welding of Mild Steel (*Revised*) with regard to its suitability for welding in these positions.

d) The electrode is suitable for welding on DC current with the electrode being positive or negative and it is also suitable for welding with AC current with open-circuit voltage of not less than 95 volts.

e) The minimum tensile strength of deposited metal is 41·0 kg/mm^2.

f) The minimum percentage elongation of deposited metal in tensile test is 26 percent.

g) The minimum impact test value of deposited metal is 4·10 kgf·m.

h) The electrode is suitable for deep penetration butt welding in the flat position and for deep penetration fillet welding in the flat and horizontal-vertical positions.

j) The electrode conforms to IS : 814-1963 Specification for Covered Electrodes for Metal Arc Welding of Mild Steel (*Revised)*.

4.4.2 *British System of Classification and Coding of Covered Electrodes for Welding Mild Steel and Low Alloy Steels* — The British system of coding is similar to the Indian system except that it does not indicate the tensile strength, percentage elongation and impact test value of the deposited metal. In this system the first letter indicates the method of manufacture as follows:

E — indicates a solid extruded electrode.

R — indicates a reinforced electrode.

D — indicates a dipped electrode.

Where the electrode is manufactured by a combination of two or more methods, the electrode is coded according to the most predominant method of manufacture.

This letter is then followed by three digits, of which

a) the *first* digit indicates the type of covering on the electrode,

b) the *second* digit indicates the welding positions in which the electrode may be used, and

c) the *third* digit indicates the current conditions under which the electrode may be used satisfactorily.

a) *Type of covering*—The first digit of the code number indicates the type of covering as follows:

Digit	*Type of Covering*
1	Indicates a covering having a high content of cellulose material
2	Indicates a covering having a high content of titania producing a fairly viscous slag
3	Indicates a covering containing an appreciable amount of titania, producing a fluid slag
4	Indicates a covering having a high content of oxides and/or silicates of iron and manganese producing an inflated slag
5	Indicates a covering having a high content of iron oxides and/or silicates producing a heavy solid slag
6	Indicates a covering having a high content of calcium carbonate and fluoride
9	Indicates a covering of any other type not classified above

b) *Welding positions* — The second digit of the code number indicates the welding positions in which the electrode may be used as followed in the Indian system.

c) *Welding current conditions* — The third digit of the code number indicates the current conditions under which the electrode may be used satisfactorily as followed in the Indian system.

If an electrode meets the requirements for deep penetration welding electrodes, this is indicated by adding the letter 'P' as suffix to the code number.

Electrodes bearing the same coding (provided the code number does not include the numeral 9) may be expected to have the major characteristics similar even though they have been produced by different manufacturers. However, there may be some difference in minor characteristics between them.

Example:

E316 — This coding is used for a solid extruded electrode, the covering of which contains an appreciable proportion of titania. The electrode produces a fluid slag and is suitable for welding in all positions but particularly recommended for vertical and overhead positions. It may be used on DC with the electrode connected to the positive or the negative pole and may also be used on AC provided the open-circuit voltage is not less than 70.

4.4.3 *American System of Classification and Coding of Electrodes for Welding Mild Steel and Low Alloy Steels* — The American Welding Society in co-operation with the American Society for Testing and Materials initiated a system of classification in which the electrodes are grouped according to (a) operating characteristics, (b) type of covering, (c) mechanical properties of deposited metal, and (d) welding current conditions.

The principle of the coding system used is relatively simple. The letter 'E' precedes the classification and indicates that the electrode is suitable for metal-arc welding. The first two digits of the electrode classification number indicate the approximate tensile strength of the weld metal in thousands of pounds per square inch. The third and fourth digits together indicate the type of covering, the welding positions in which the electrode may be used, and current conditions for which the electrode is suitable.

The grouping according to mechanical properties covers a tensile strength range from 45 000 to 120 000 pounds per square inch and the respective code references are:

E45XX, E60XX, E70XX, E80XX, E90XX, E100XX, and E120XX

The third and fourth digits together indicate the following characteristics irrespective of tensile strength of the weld metal:

a) Classification EXX10 designates an electrode having a covering with a high content of cellulose, bonded with sodium silicate. It is suitable for welding in all positions but it is recommended for use with direct current only, with the electrode connected to the positive pole. The nearest Indian coding is E110XXXP.

b) Classification EXX11 designates an electrode having a covering similar to that used for the EXX10 class but bonded with potassium silicate. It is suitable for welding in all positions and it is recommended for use with alternating current and also direct current with the electrode connected to the positive pole. The nearest Indian coding is E111XXXP.

c) Classification EXX12 designates an electrode having a covering with a high content of rutile, bonded with sodium silicate. It is suitable for welding in all positions and is recommended for use with alternating current and also direct current with the electrode connected to the negative pole. The nearest Indian coding is E213XXX.

d) Classification EXX13 designates an electrode having a covering similar to that used for EXX12 but with the increased addition of arc stabilizing compounds. It is suitable for welding in all positions and is recommended for use with alternating current as well as direct current with the electrode connected to the negative pole. The nearest Indian coding is E313XXX.

e) Classification EXX15 designates an electrode having a low hydrogen type of covering of the lime ferritic type bonded with sodium silicate. It is suitable for welding in all positions but is recommended for use with direct current only with the electrode connected to the positive pole. The nearest equivalent Indian coding is E610XXX.

f) Classification EXX16 designates an electrode having a low hydrogen type of covering similar to that used for EXX15 class but bonded with potassium silicate. It is suitable for welding in all positions and is recommended for use with alternating current as well as direct current with the electrode connected to the positive pole. The nearest Indian coding is E611XXX.

g) Classification EXX20 designates an electrode having a covering with a high content of iron oxide. It is suitable for welding in the flat and horizontal-vertical positions and is recommended for use with alternating current as well as direct current with the electrode connected to either pole. The nearest Indian coding is E426XXX.

h) Classification EXX24 designates an electrode with a large amount of iron powder and other fluxing ingredients similar to EXX13 class. It is suitable for flat and horizontal-vertical fillet welds at high lineal speed and may be used with DC with the electrode connected to the positive or negative or with AC.

j) Classification EXX27 designates electrodes having a covering of large amount of iron powder and fluxing ingredients similar to EXX20 class. Applications are similar to class EXX20.

k) Classification EXX30 designates an electrode having a covering with a high content of iron oxide but producing a less fluid slag than the EXX20 electrode. It is suitable for welding in the flat position only and is recommended for use with alternating current as well as direct current with the electrode connected to either pole. The nearest Indian coding is E436XXX.

4.5 Deep Penetration Electrodes

Deep penetration electrodes are specially designed to give a greater depth of fusion than that given by the conventional electrodes. The deep penetration properties are used for butt welds in the flat position and fillet welds in the flat and horizontal-vertical positions. The penetration requirements for deep penetration electrodes are as follows:

a) *Deep Penetration Electrodes for Close Square Butt Welding in Flat Position* — When using the current conditions and welding technique recommended by the manufacturer of the electrode, a deep penetration electrode shall provide a minimum penetration equal to at least half the plate thickness when the electrode is continuously deposited in a close square butt joint between two plates,

   1) each of a thickness equal to twice the core diameter of the electrode used in the case of electrodes of diameter less than 6 mm, and

   2) each of a thickness equal to 12 mm in the case of electrodes of diameter 6 mm or more.

b) *Deep Penetration Electrodes for Fillet Welding in Flat and Horizontal-Vertical Positions* — When using the current conditions and welding technique recommended by the manufacturer of the electrode, a deep penetration electrode shall provide a minimum penetration of 2·4 mm beyond the root when the electrode is continuously deposited in a close square tee-joint between two plates, each of a thickness equal to twice the core diameter of the electrode (*see* Fig. 35).

Deep penetration electrodes are often of the following types of coatings:

a) Coating having high cellulosic content,

b) Coating having a high content of iron oxides or silicates, and

c) Coating having iron powder.

Cellulosic types generally possess a digging arc and intense heat is produced due to higher arc voltages.

Electrode coating having a high content of iron oxides or silicates withstands very high currents and the deep penetration technique consists in using very high currents and high welding speeds. For example, exceptionally deep penetrations are claimed for fillet welds using 6-mm electrode at 425 amperes at a welding speed of 300 mm per minute.

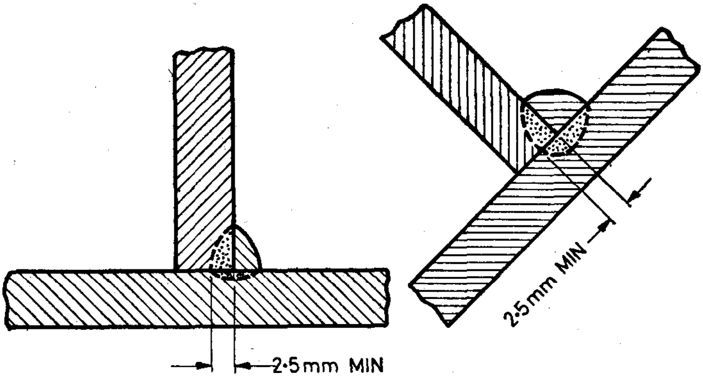


FIG. 35 DEEP PENETRATION FILLET WELD

Iron powder types also owe their deep penetration properties for being able to withstand high currents. A typical procedure for obtaining full penetration butt weld up to 20 mm without the necessity of bevelling is as follows:

Plate Thickness mm	*Root Gap* mm	*Size of Electrode* mm	*Current Range* A
Up to 8	1·6 to 2·4	3·2	160 to 180
8 „ 12	„	4	200 „ 240
12 „ 20	„	5	270 „ 310

It should, however, be borne in mind that the base material should be mild steel or medium tensile steel of weldable quality with low values for carbon and sulphur. If the carbon is high, the weld metal will pick up the same and become hard and brittle, while high sulphur pick-up will lead to porosity and sometimes to hot cracking of the weld.

4.6 Special Electrodes

Electrodes other than mild steel are commonly called 'special electrodes'. These may be grouped as follows:

a) Low alloy high-tensile steel electrodes,
b) Hardfacing electrodes,
c) Stainless steel electrodes,
d) Non-ferrous electrodes, and
e) Electrodes for cast iron welding.

4.6.1 *Low Alloy High-Tensile Steel Electrodes* — These electrodes are designed to give low alloy weld deposits having higher tensile strength than mild steel, that is, 55 kg/mm^2 and higher. The common alloying elements present in these electrodes are manganese, chromium, nickel, molybdenum, vanadium and silicon. These elements may be present either in the core wire or in the flux coating. In the case of more common alloy steel electrodes, the core wire itself is of alloy steel. Normally the core wire is of mild steel, and the flux coating contains all the necessary alloying elements which pass into the weld deposit during welding.

Low alloy high-tensile steel electrodes may have a flux coating of the cellulosic type, rutile type or low-hydrogen type. Where the alloying elements are in large quantities, the electrode is mostly provided with a low-hydrogen coating as the transfer of alloying elements across the arc is more efficient. Welds made on high-tensile steels with this type of electrode are less sensitive to cracking than when other types of coatings are used.

These electrodes find application on pipe lines carrying hot liquids and steam, on boilers, armour plates, and in structural work where high-tensile steels are used. Examples of such electrodes are molybdenum steel (0·5 percent molybdenum and 0·8 percent manganese) electrodes, chromium-molybdenum steel (one percent chromium and 0·3 percent molybdenum) electrodes, and chromium-molybdenum nickel steel (one percent chromium, 2·5 percent nickel and 0·7 percent molybdenum) electrodes. The Cr-Mo-Ni steel electrodes give a tensile strength of about 95 kg/mm^2.

4.6.2 *Hardfacing Electrodes* — Hardfacing electrodes are used for giving a hard, wear-resistant surface on components which are subject to wear and tear in service. For application on mild steel components, three types of electrodes are commonly used. These give a weld deposit having 250, 350 and 650 Brinell hardness respectively. The weld deposit is sufficiently high in carbon, chromium and other elements to enable it to harden while cooling in air. Weld deposit of 250 Brinell hardness is easily machineable, that of 350 Brinell hardness is machinable only with special tools and that of 650 Brinell hardness is not at all machinable and has to be finished by grinding. The first one is suitable for gear teeth and shaftings, the second one for railway points and crossings, and the third one for earth-moving equipment and oil expeller worms.

There are other hardfacing electrodes for special applications, for example, electrodes giving an austenitic manganese steel deposit with about 13 percent manganese are used for surfacing jaws of stone crushers and other components made of austenitic manganese steel. Special stainless steel electrodes are used for joining stainless steel, heat-resisting steels and austenitic manganese steel to mild steel. Electrodes giving tool steel deposits are used for producing cutting tips on steel shanks and for repairing tool steel bits.

There are also electrodes giving a deposit high in tungsten and cobalt for building up parts which are subject to heavy friction, corrosion and heat, such as, stamping dies, hot shearing blades, etc.

4.6.3 *Stainless Steel Electrodes* — Stainless steel electrodes have a stainless steel core wire and a flux coating of the rutile type or low-hydrogen type. The former may be used on AC or DC while the latter may be used only on DC. The three most common grades are 18 percent chromium, 8 percent nickel; 18 percent chromium, 8 percent nickel, 2·5 percent molybdenum; and 25 percent chromium, 20 percent nickel. For application on chemical plant under corrosive conditions, the weld metal is stabilized with niobium (that is, columbium). Such stabilization is necessary to prevent extreme corrosion in the region next to the weld, a phenomenon known as 'weld decay'.

4.6.4 *Non-ferrous Electrodes* — Electrodes which come under this heading are of copper and copper alloys, aluminium and aluminium alloys, and nickel and nickel alloys. In these, the core wire itself has the composition of the weld deposit desired, and the flux coating merely serves to stabilize the arc, control the weld bead, and prevent loss of alloying elements in the arc. These electrodes are meant usually to be used on direct current.

4.6.5 *Electrodes for Cast Iron Welding* — There are four distinct types of electrodes commonly used for cast iron welding. One of them, having a mild steel core wire, gives a very hard and non-machineable deposit. The second type is the cupro-nickel or monel electrode, the weld deposit for which is machineable. The third type is a pure nickel electrode which is also used in the same manner as the cupro-nickel electrode and gives a machineable deposit. The fourth type is a nickel iron alloy electrode which gives a machineable deposit and is particularly suitable for welding spheroidal graphite iron castings.

4.7 Care in Handling and Storage of Arc Welding Electrodes

Arc welding electrodes require special care in handling and storage to ensure that the flux coating may retain its original strength of bonding over long periods and give satisfactory welds in use. Rough handling, improper storage and storing electrodes over prolonged periods in moist conditions will cause the coating to peel off, rendering them useless. Flux coatings are not hygroscopic, but when the atmosphere is humid the moisture gets deposited in the minute pores of the flux coating. The moisture is driven out when the atmospheric humidity falls or the storage room is heated. Electrode coatings are thus able to breathe freely, that is, they will absorb or throw out moisture from their pores depending on the rise or fall of atmospheric humidity.

During the rainy season, when storage rooms are expected to be very humid, it is advisable to heat up and maintain a room temperature of at least 10° to 20°C higher than the outside temperature. Where heating of the storage room is not practicable, a freely-ventilated storage room is to be preferred. Electrodes which have been rendered wet by direct exposure to water should be re-dried according to manufacturer's recommendation before use. Excessive drying of rutile and cellulosic types of electrodes is not advisable as reasonable amount of moisture is necessary to help thorough and even fusion of the coating in the arc during welding. On the other hand, welding with moist electrodes gives a fierce arc and a weld deposit saturated with hydrogen which is very susceptible to cracking. An experienced welder is able to detect these extreme conditions at once, because, besides other things the fluidity of the slag in the molten pool will be abnormal.

When electrodes remain in a moist condition over a long period, the water lodged in the pores of the coating causes the core wire to rust. This rust starts spreading out and eventually disrupts the coating at several places. Welds made from such electrodes will not give a steady arc and the mechanical properties of the weld metal will be lower than those claimed by the manufacturer. Electrodes stored under normal conditions over long periods develop a white crust on their outer surface. This crust is an alkaline carbonate formed by the action of atmospheric carbon dioxide on the alkaline silicate binder, and is harmless.

Electrodes should be retained in their original manufacturer's packing until taken out for use. Electrodes are generally supplied in cardboard cartons or tin containers on which is shown the batch number of the manufacturer. This number should be retained until the electrodes have been used up, as this is needed when making references with regard to these electrodes to the manufacturer. Stocking electrode cartons directly on the floor should be avoided, as also piling too many of them one above the other because the electrodes at the bottom may get crushed due to the weight above. It is a good practice to stock electrode in shelves, separately according to their sizes, types and batches.

The low-hydrogen or basic electrodes do not tolerate even a trace of moisture. Such electrodes are always supplied in sealed, air-tight containers and should be so retained until taken out for use. Any electrode left over from an opened container should be stored in an oven maintained at about 150°C. It is possible to recondition low-hydrogen electrodes exposed to moisture for a long time only by re-heating them at a temperature of over 350°C for 15 to 20 minutes. This is especially necessary when the electrodes are for use on high-tensile and high-alloy steels.

Electrodes should not be thrown around or dropped from a height as the coating may break. Electrodes from which the coating has come off at places should not be used. This is specially so where the flux coating contains alloying elements meant to modify the composition of the deposit. Electrodes should be used up to within 50 mm, that is, the stub length should not exceed 50 mm.

SECTION 5

WELDING POSITIONS AND TYPES OF WELD

5.1 Welding Positions

It has been mentioned in Section 4 on electrodes that the second digit of the code number in the Indian system of classification of electrodes indicates the welding positions in which the electrode may be used conveniently. These positions will now be defined and explained.

There are five recognized positions and these are:

a) Flat or downhand position,
b) Inclined position,
c) Horizontal-vertical position,
d) Vertical position, and
e) Overhead position.

A few common weld joints in these five positions are illustrated in Fig. 36.

These welding positions have been fixed in relation to the weld slope and weld rotation which are explained below:

a) *Weld Slope* is the angle formed between the line of the weld root and the horizontal reference plate (*see* Fig. 37).
b) *Weld Rotation* is the angle formed between the upper portion of a vertical reference plane passing through the line of the weld root and that part of a plane passing through the weld root and a point on the face of the weld equidistant from both edges of the weld (*see* Fig. 38).

Example illustrating the weld slope and weld rotation is given in Fig. 39.

It is now possible to define the five welding positions in terms of slope and rotation as indicated in Table II.

TABLE II DEFINITIONS OF WELDING POSITIONS

POSITION (1)	SYMBOL (2)	SLOPE (3)	ROTATION (4)	ILLUSTRATION (REF TO FIG.) (5)
Flat or downhand	F	Not exceeding 10°	Not exceeding 10°	40
Inclined	I	Exceeding 10° but not exceeding 45°	Not exceeding 90°	41
Horizontal-vertical	H	Not exceeding 10°	Exceeding 10° but not exceeding 90°	42
Vertical	V	Exceeding 45°	Any	43
Overhead	O	Not exceeding 45°	Exceeding 90°	44

NOTE — The five positions defined in Table II cover any possible combination of slope and rotation so that it is possible to classify every weld in one of these positions.

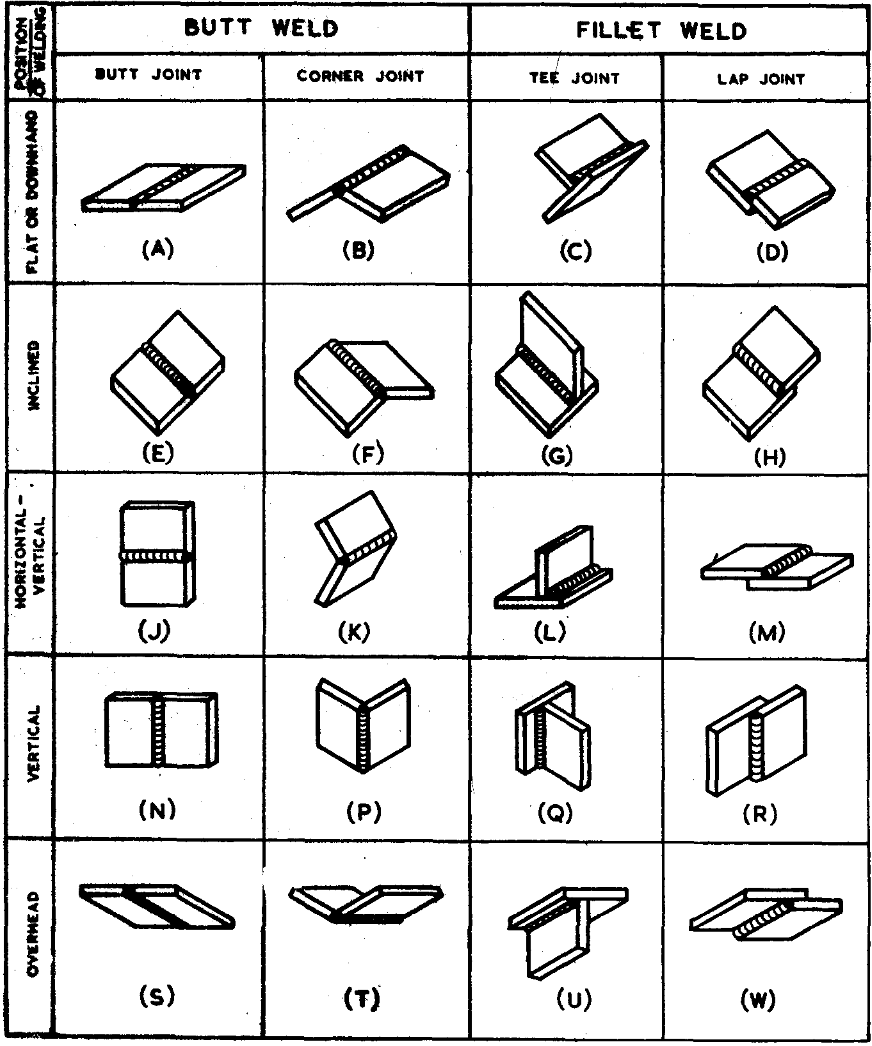


Fig. 36 Positions of Welding

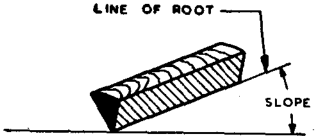


FIG. 37 WELD SLOPE

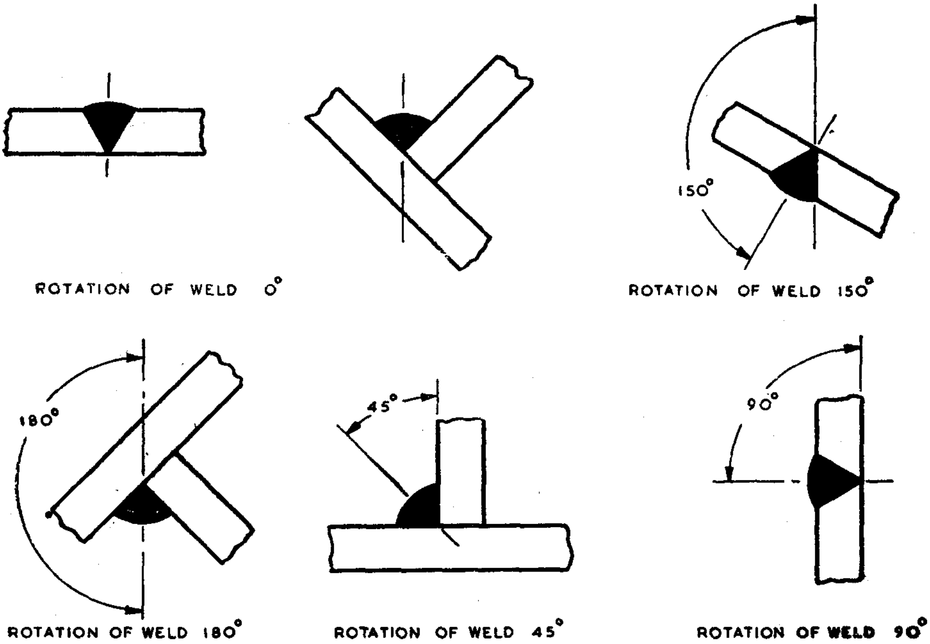


FIG. 38 WELD ROTATION

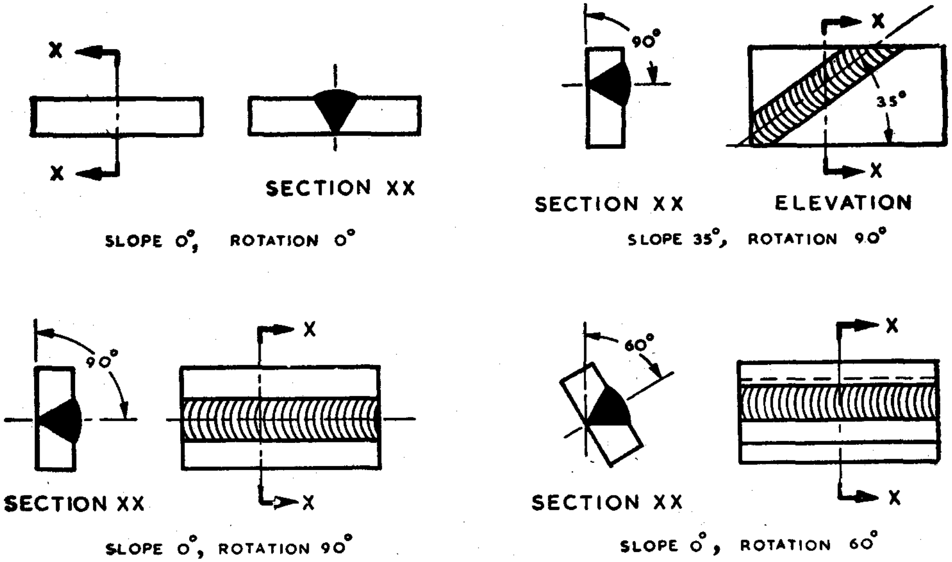


Fig. 39 Slope and Rotation

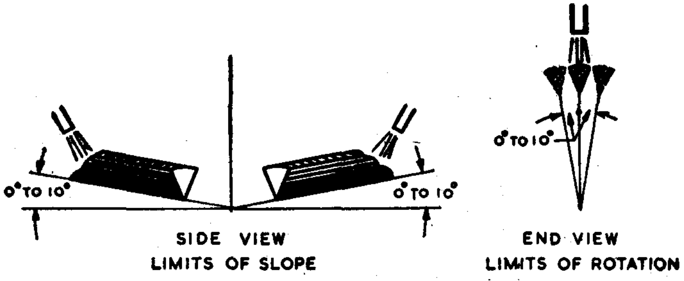


Fig. 40 Weld in Flat Position

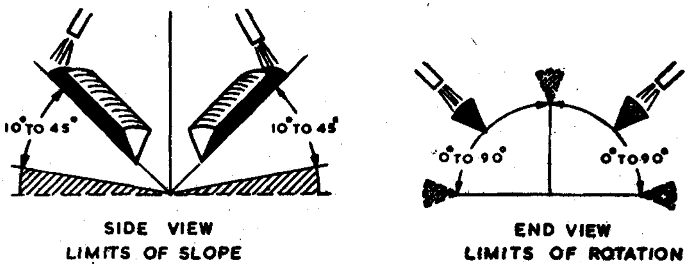


Fig. 41 Weld in Inclined Position

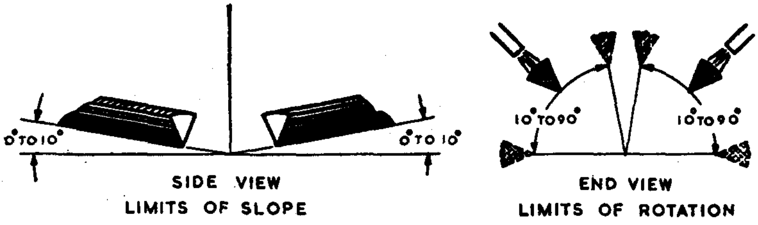


FIG. 42 WELD IN HORIZONTAL-VERTICAL POSITION

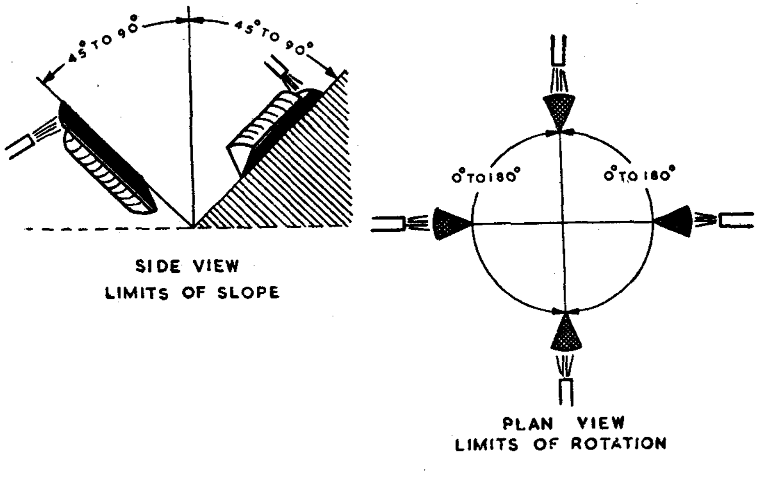
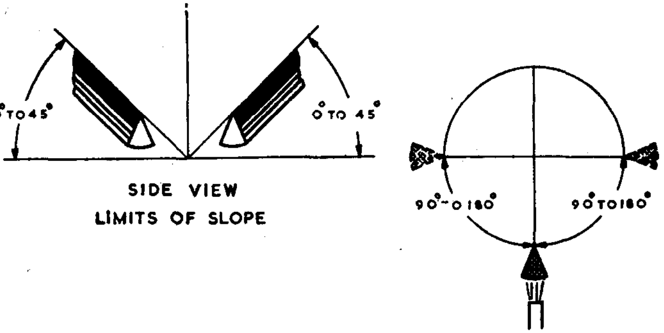


FIG. 43 WELD IN VERTICAL POSITION



SIDE VIEW
LIMITS OF SLOPE

END VIEW
LIMITS OF ROTATION

FIG. 44 WELD IN OVERHEAD POSITION

An electrode is not classified as suitable for a particular welding position unless it is possible to use it satisfactorily in that position to give the best results complying with the requirements of the appropriate Indian Standard. Where an electrode is classified as suitable for vertical and overhead positions, it should be understood that sizes 5 mm and below are used generally for welding in these positions.

The flat or downhand position is the easiest position to weld. The maximum production rate is obtained in this position, with least fatigue to the welder. It is also easier to obtain sound welds in this position. Suitable welding positioners, and rotators make it possible to weld most of the jobs in the flat position.

It is easier to make inclined welds up the slope than down the slope. When welding down the slope, a smaller diameter electrode with quick freezing slag may be necessary to avoid the interference of the slag in the arc.

It is possible to make horizontal-vertical welds in tee joints and lap joints as easily with large size electrodes as those in the flat position. For butt joints, especially on thinner sections, additional skill is necessary and use of only 5 mm and smaller electrodes is permissible.

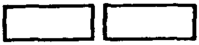
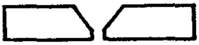
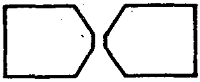
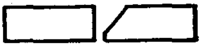
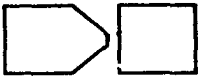
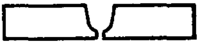
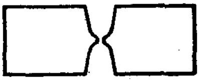
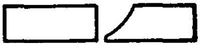
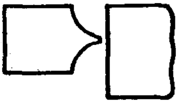
The technique of making welds in various positions is explained in Section 6.

5.2 Types of Joints and Welds

The types of joints normally met with in practice and the types of welds applicable for each type of joint are enumerated in Table III.

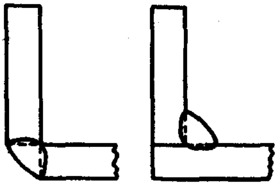
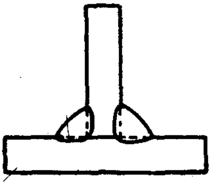
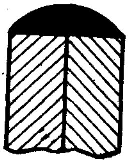
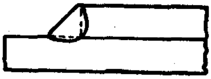
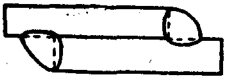
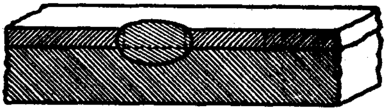
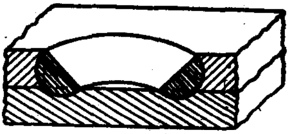
TABLE III TYPES OF JOINTS AND TYPES OF WELDS APPLICABLE TO EACH TYPE OF JOINT

(*Clause* 5.2)

TYPE OF JOINT	TYPE OF WELD APPLICABLE	ILLUSTRATION
Butt joint	Square	
	Single-V	
	Double-V	
	Single bevel	
	Double bevel	
	Single-U	
	Double-U	
	Single-J	
	Double-J	

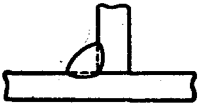
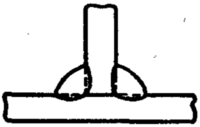
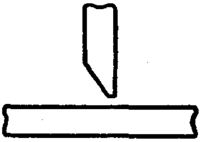
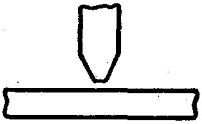
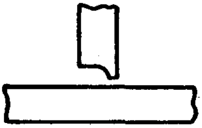
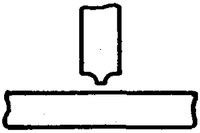
(Continued)

TABLE III TYPES OF JOINTS AND TYPES OF WELDS APPLICABLE TO EACH TYPE OF JOINT—*Contd*

TYPE OF JOINT	TYPE OF WELD APPLICABLE	ILLUSTRATION
Corner joint	Single fillet	
	Double fillet	
Edge joint	Bead	
Lap joint	Single fillet	
	Double fillet	
	Plug	
	Slot	

(*Continued*)

TABLE III TYPES OF JOINTS AND TYPES OF WELDS APPLICABLE TO EACH TYPE OF JOINT—*Contd*

TYPE OF JOINT	TYPE OF WELD APPLICABLE	ILLUSTRATION
Tee-joint	Single fillet	
	Double fillet	
	Single bevel	
	Double bevel	
	Single-J	
	Double-J	

SECTION 6

WELDING PROCEDURES AND TECHNIQUES

6.1 General

In order to achieve good results in a welding job, it is essential first to lay down the correct welding procedure for a particular job and then to ensure that the operator follows the correct technique in carrying out the procedure. The choice of the procedure and technique for making a particular weld depends on the material, its thickness, the type of work, and the mechanical properties required at the joint.

6.2 Welding Procedure

Welding procedure could be described as a specified course of action to be followed in welding. In the case of arc welding, the following course of action is to be followed:

a) Classification and size of electrode;
b) Current and open-circuit voltage;
c) Length of run per electrode, or speed of travel;
d) Number and arrangement of runs in multi-run welds;
e) Position of welding;
f) Preparation and set up of parts;
g) Welding sequence; and
h) Pre-heating or post-heating.

In order to determine correct limiting values in respect of each of the factors mentioned above, one has to be aware of the effect of each factor on the ultimate quality of the welded joints.

6.2.1 *Classification of Electrodes* — Before drawing up a welding procedure the characteristics of each class of electrode are to be borne in mind to enable one to specify a particular class of electrode for a particular type of joint depending upon the requirements. In a complicated structure, for example, electrode with Type 4 covering (Indian system) (*see* Section 4) may be specified for a long, heavy fillet weld in the horizontal position, electrode with Type 1 covering for a multi-pass weld in the overhead position in a joint of good fit-up, electrode with Type 3 covering for a multi-pass weld in the vertical joint with poor fit-up, and a special iron-powder deep-penetration electrode for heavy joints in the flat position without the necessity of bevelling.

6.2.2 *Electrode Size* — The size of the electrode to be used is determined by the thickness of the section. The aim should always be to use as large an electrode as possible determined by the size of the joint, as this leads to faster welding with lesser interruptions and less distortion. Where the rigidity of a structure confers large stresses on the weld, a weld made with larger size of electrode is more resistant to cracking than that made with a smaller size. A root run in a butt joint of size up to 6 mm should be made with a 4-mm electrode. In the case of thicker joints a 5-mm electrode should be used for the root run. In both the cases the rest of the passes may be made with a 6-mm or 8-mm electrode. In order to observe these conditions the butting faces should not be bevelled to a feather-edge. The root gap should be maintained within limits. Where limitation of equipment prevents good bevelling and fit-up of joints, copper backing may be provided under the joints.

In vertical and overhead positions, the maximum size of electrode that may be used is restricted. It is not possible to make a root pass in a vertical fillet weld with an electrode larger than 4 mm unless the sections are heavy enough to make the weld metal freeze quickly. Hence, it is preferable to use welding positioners to bring the joint to be welded into the down-hand position.

6.2.3 *Current and Open-Circuit Voltages* — The current values should be so chosen that the electrode gives a steady rate of fusion with least spatter and it should be possible to use the electrode completely without getting red-hot. Usually, the electrode manufacturers state the welding current range for each type and size of electrode. These limits should be adhered to. In addition to the control of the welding current, the welder should also adopt the correct type of current (AC or DC), the polarity of the electrode (negative or positive), and the open-circuit voltage. These conditions are conveyed in the coding of the electrode and specified by the manufacturer.

6.2.4 *Length of Run* — The length of run per electrode or speed of travel has to be chosen depending on the type and size of electrode as these factors determine the cross-section of the bead, the degree of fusion, the contour and appearance of the weld surface. When the arc is moved slowly, there is a pool of molten metal under the arc, and the force of the arc is expanded on the molten pool instead of penetrating into the parent metal at the root of the joint. This molten metal merely flows along the joint under the arc tending to solidify in the root of the weld without fusion with the parent metal. It is apparent that to get greater penetration and to ensure proper fusion, the arc should be advanced more rapidly rather than more slowly. This limiting speed is usually the highest speed at which the surface appearance remains satisfactory. The effects of using incorrect currents and speeds of travel are illustrated in Fig. 45.

6.2.5 *Number and Arrangement of Runs* — The number of runs in a multi-run weld should be kept to the minimum by using the largest possible size of electrode, the least angle of bevel (usually 30°) and minimum root gap. The number and arrangement of runs in butt joints and tee-joints from 3 mm to 25 mm are given in Tables IV and V.

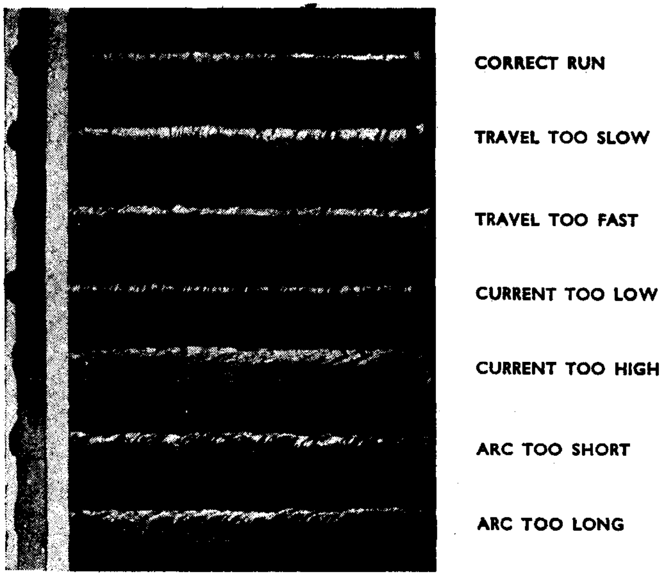


Fig. 45 Welds Made Under Different Conditions

6.2.6 *Position of Welding* — Though electrodes are available for use in all positions, it is desirable to make the welds in the flat position. Welding positioners and manipulators are used to bring the joints to be welded into the flat position. Illustrations of typical welding positioner and manipulator are given in Fig. 46 and Fig. 47 respectively.

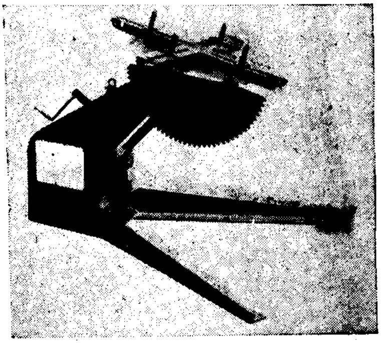


Fig. 46 Typical Welding Positioner

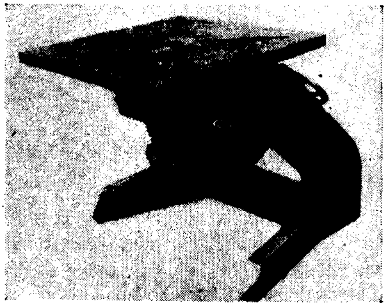
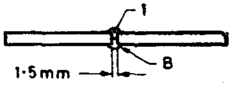
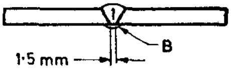
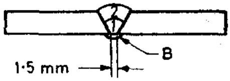
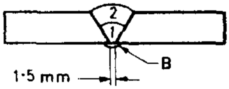
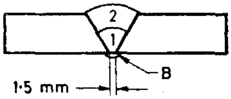
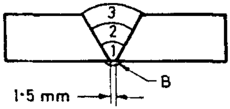
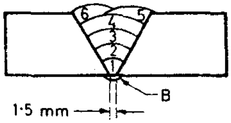
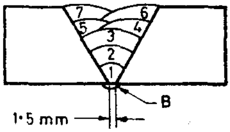
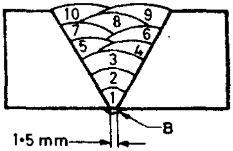


Fig. 47 Welding Manipulator

TABLE IV NUMBER AND ARRANGEMENT OF RUNS IN BUTT WELDS (HEAVY-COATED ELECTRODES)

(*Clause* 6.2.5)

Butt Welds (vees 60°)

Plate Thickness mm	Procedure	No. of Runs	Size of Electrode mm	Approx Current A
3		1	3·2	90
4		1	4	170
6		1 1	4 5	170 200
8		1 1	5 6	200 320
10		1 1	5 6	200 320
12		1 2	5 6	200 320
16		1 5	5 6	200 320
20		1 6	5 6	200 320
25	 10 8 9 7 6 5 4 3 2 1 B 1·5 mm	1 9	5 6	200 320
B=Back sealing run (applied downhand).		1	5	200

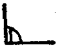
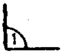
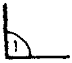
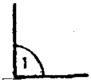
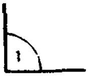
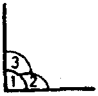
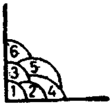
NOTE — All slag and irregularities on back to be removed before making sealing run B.

TABLE V NUMBER AND ARRANGEMENT OF RUNS IN FILLET WELDS (HEAVY-COATED ELECTRODES)

(*Clause* 6.2.5)

Fillet Welds (End or Side)

NOTE — Legs to be equal and reinforcement a minimum.

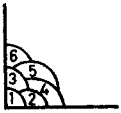
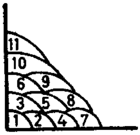
PLATE THICKNESS mm	PROCEDURE	NO. OF RUNS	SIZE OF ELECTRODE mm	APPROX CURRENT A	ALTERNATIVE PROCEDURE WHERE BASE METAL IS THINNER THAN 10 mm		
					Runs	Size of Electrode mm	Approx Current A
3		1	4	160	—	—	—
4		1	5	200	—	—	—
6		1	6	320	1	5	200
8		1	6	320	1	5	200
10		1	6	320	3	5	200
12		1 2	5 6	200 320	—	—	—
16		6	6	320	—	—	—

(*Continued*)

TABLE V NUMBER AND ARRANGEMENT OF RUNS IN FILLET WELDS (HEAVY-COATED ELECTRODES)—*Contd*

Fillet Welds (End or Side)

NOTE — Legs to be equal and reinforcement a minimum.

PLATE THICKNESS	PROCEDURE	NO. OF RUNS	SIZE OF ELECTRODE	APPROX CURRENT	ALTERNATIVE PROCEDURE WHERE BASE METAL IS THINNER THAN 10 mm		
mm			mm	A	Runs	Size of Electrode mm	Approx Current A
20		6	6	320	—	—	—
25		11	6	320	—	—	—

6.2.7 *Preparation and Set Up of Parts* — The selection of the type of weld to be used is based largely from the point of economy. The square butt weld is the most economical to use, since this weld requires no chamfering, provided satisfactory strength is attained. Joints have to be bevelled when the parts to be welded are so thick that most of the joints have to be made accessible for welding in order to obtain the required strength. In the interest of economy, joints for vee and bevel butt welds should be selected with minimum root openings and groove angles such that the amount of weld metal to be deposited, is the smallest. J- and U-butt joints may be used to further minimize weld metal when the savings are sufficient to justify the more difficult and costly chamfering operations. The J-joint is usually used in fillet welds.

The edges, wherever possible, should be machined or machine-oxygen cut to provide a straight, uniform and smooth contour for welding. On sheared edges, sufficient metal should be removed in subsequent scarfing to assure freedom from shear, drag and tear. Irregular edges are chamfered by chipping, manual or portable machine-oxygen cutting, and should be carefully laid out using templates wherever possible. Groove contours should be carefully and continuously checked with gauges, and inaccuracies corrected by grinding to remove the excess metal.

Bevelling thick sections to feather-edge should always be avoided and a 3-mm shoulder provided. The feather-edge compels the first run to be made with a relatively small electrode (unless a backing plate is used) and this bead of small cross-section in the root is easily susceptible to cracking. A cracked root run may become the starting point of a major failure even though subsequent heavy beads have apparently hidden it. The root gap is recommended since the spacing allows the shrinking weld to draw the plates freely together unless they are constrained by clamps used in jigs or fixtures. Thus, it is possible to reduce weld cracking and minimize distortion.

Surface for welding should be examined for surface defects such as scale, pits, laminations, etc.

In all welds made from both the sides, the root of the weld deposited from the first side should be cleaned out by oxygen gouging or chipping before commencing welding from the other side. In this operation workmanship is of utmost importance. The flame or tool should leave a semicircular groove into which it is possible to deposit the weld metal from the second side. The groove should be deep enough to expose the solid weld metal after removing all slag or dirt entrapped in the root of the first side.

Parts to be welded should be carefully aligned and tacked. To avoid possible flaws at tack welds, various types of clamps are used and these assist in maintaining the correct root spacing and alignment of edges. Some of these are tack welded to one or both the plates, others employ friction from the loading of bolts or wedges. Tack welds on clamps are usually removed after welding is sufficiently completed. Localized distortion should be corrected by jacks and struts or by local heating, instead of hammering. However, in the interest of economy and safety in service, distortion should be prevented wherever possible. Before jacking, and in general where welding or other operations have accumulated stress or noticeable distortion, stress relief may have to be resorted to.

6.2.8 *Welding Sequence* — A proper sequence of welding is necessary to avoid excessive restraint on the weld and to facilitate the deposition of sound metal. In some important construction works, such as in ship-building, certain general rules of welding sequence have become accepted on the basis of long experience. Some rules, for example, are based on the principle of welding towards the free ends, or in the direction of the greatest freedom. Another rule is to weld a structure in sub-assemblies before tying them up into one integrated structure.

6.2.9 *Heat-Treatment* — Heat-treatment is sometimes necessary for making efficient welded joints and carrying out successful repair on metallic components. Heating carried out before the commencement of welding and during the period of welding is termed as pre-heating. Heating carried out after the completion of the weld is called post-heating.

Pre-heating may be necessary for the following reasons:

a) To slow down the cooling rate of the deposited weld metal and the heat affected zone of the parent metal. Pre-heating in this case prevents undue hardening and cracking of the weld metal and the heat-affected zone. Pre-heating is often called for in the welding of heavy mild steel sections, before making a root pass in a heavy tee-joint and in the welding of high-tensile steels, such as armour plates.

b) Pre-heating of the entire base metal may be necessary to distribute the expansion and contraction stresses caused by welding as in the case of cast iron which has poor ductility.

c) Pre-heating may be necessary to maintain sufficient heat at the joint to ensure proper fusion. Difficulty is often experienced in welding metals having high thermal conductivity such as copper, aluminium, stainless steel, etc, in which case heat of the arc is rapidly conducted away by the parent metal.

d) Local pre-heating may be done to cause initial expansion in one direction so that it will later balance the expansion and contraction caused by welding. For example, in repairing, fractures in wheels and pulleys.

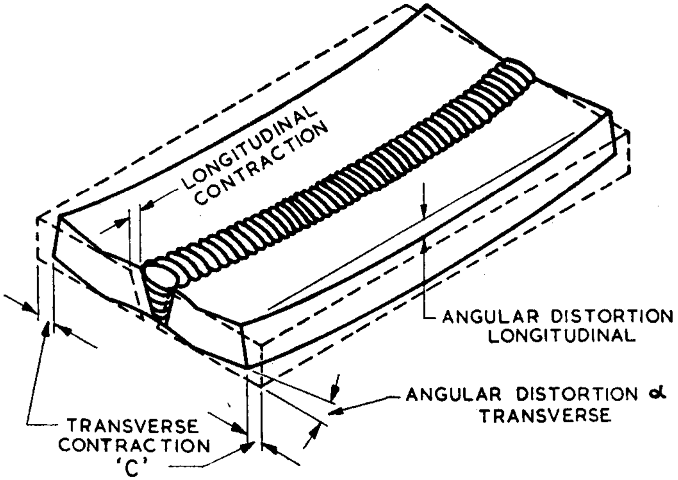
6.3 Welding Technique

Welding technique comprises the method of striking the arc, maintaining the correct arc length and angle of electrode and weaving of the electrode depending upon the type of electrode, weld joint and the welding position. The welder has to adopt the correct welding technique in order to produce a sound weld in the most economical manner. The set of exercises prescribed in IS : 817-1957 Code of Practice for Training and Testing of Metal Arc Welders would enable the welder to acquire the correct welding technique.

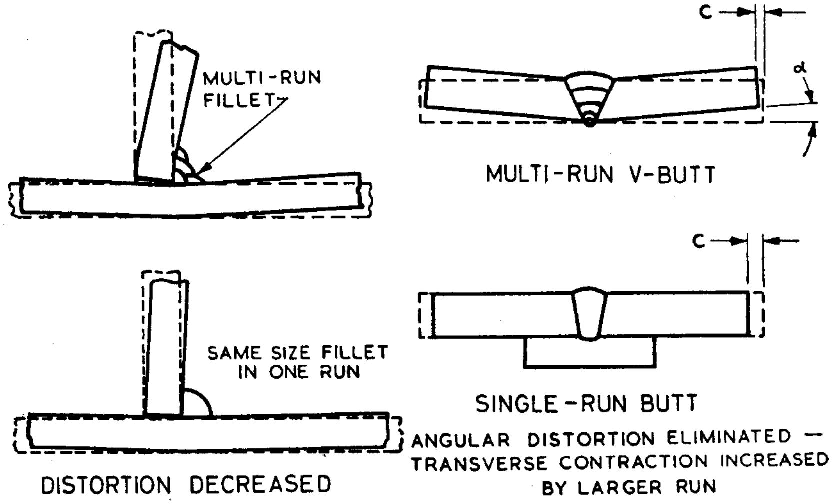
6.4 Distortion and Its Control by Correct Welding Technique and Procedure

It is a matter of common knowledge that all metals expand when heated and contract when cooled. In arc welding the heat of the arc causes the weld metal and the adjoining parent metal to expand. This is followed by cooling of the parent metal and the weld deposit which causes contraction. This expansion followed by contraction causes distortion of the workpiece. Distortion may take place in various directions as shown in Fig. 48.

The first run in a butt weld pulls the plates together. The second run tries to do so but it is restrained by the run underneath which has to be compressed before the plates come any closer. The pull at the top and the push at the bottom of the weld give rise to 'angular distortion'. A number of superimposed runs all trying to contract together with the initial contraction of the first run, cause a 'transverse contraction' of the joint (*see* Fig. 48).


LONGITUDINAL CONTRACTION
ANGULAR DISTORTION LONGITUDINAL
ANGULAR DISTORTION α TRANSVERSE
TRANSVERSE CONTRACTION 'C'

DISTORTION IN BUTT WELD



MULTI-RUN V-BUTT

SINGLE-RUN BUTT

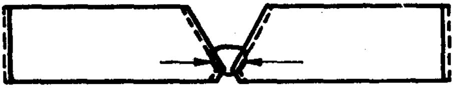
ANGULAR DISTORTION ELIMINATED — TRANSVERSE CONTRACTION INCREASED BY LARGER RUN

DISTORTION DECREASED

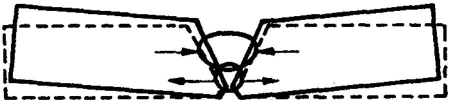
DEFECT OF RUN, SHAPE AND SIZE

FIG. 48 DISTORTION DUE TO WELDING

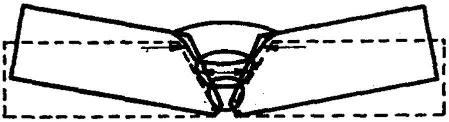
Similar forces act along the length of the joint producing lengthwise distortion and 'longitudinal contraction' (*see* Fig. 49).



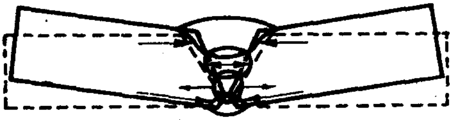
FIRST RUN CONTRACTS AND DRAWS PLATES TOGETHER



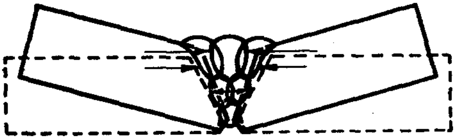
CONTRACTION OF SECOND RUN IS OPPOSED BY FIRST RUN



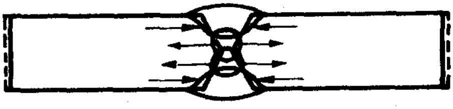
CONTRACTION OF THIRD RUN INCREASES ANGULAR DISTORTION



COMPLETION OF BACK RUN LEAVES CENTRE OF WELD IN COMPRESSION, OUTSIDE OF WELD IN TENSION



WHEN THE WELD IS MADE IN A NUMBER OF SMALL RUNS THE DISTORTION IS GREATER



THE USE OF A DOUBLE-V AND SYMMETRICAL WELDING ELIMINATES ANGULAR DISTORTION AND PRODUCES ONLY A SMALL TRANSVERSE CONTRACTION

FIG. 49 DISTORTION DUE TO CONTRACTION OF THE WELD METAL

Almost every job has its own problem of distortion and this should be dealt with on its own merits. In arc welding the heat is more localized than in oxy-acetylene welding and, therefore, distortion is less.

The amount of distortion produced on a welded job depends upon:

a) the amount of weld metal deposited,

b) the number of runs,

c) the extent to which parts are free to move, and

d) the original condition of the parts to be welded.

A large weld will shrink more than a small one. If the first run in a butt weld were made over a root gap of 6 mm the shrinkage would be more than that of a run over a gap of 3 mm.

One run exerts a straight pull. Two runs exert a push and pull together, causing bending. Additional runs on top of these increase the forces causing bending.

The plates may be forcibly held in position while the welding is being done. When the contraction of the weld is thus restrained, distortion is reduced. Preventing contraction is equivalent to stretching (or straining) the cold metal. As such when there is an alteration in length (strain) there is a corresponding force (stress). Therefore, it is apparent that in welding a restrained joint, internal stresses are set up. These are called cooling stresses, contractional stresses, locked up stresses, or residual stresses. The last term is usually employed as it covers the general case of an internal stress remaining when all external forces are removed. The residual stresses in restrained joints are higher than those in joints which are free to distort during welding. The effects of these residual stresses are to increase the possibility of cracks or premature failures, to reduce the fatigue strength of the joint, and to increase the tendency to distort on subsequent heating or during machining.

The correct procedure tends to decrease distortion and it should be remembered that large electrodes introduce less heat in proportion to the amount of metal deposited and consequently cause less distortion.

6.5 Control of Distortion and Residual Stress by Proper Welding Technique

As either distortion or residual stress, or more commonly a combination of both, occur in every welded joint, it is necessary to control them.

6.5.1 *Prevention and Control of Distortion* — The following three simple rules will help materially in the prevention and control of distortion:

Rule 1 — Reduction of the effective shrinkage force.
Rule 2 — Making the shrinkage forces work to reduce distortion.
Rule 3 — Balancing one shrinkage force with another shrinkage force

6.5.1.1 Reduction of the effective shrinkage force may be achieved by the following methods:

a) *Overwelding should not be done* — Addition of excess of weld metal over and above the service requirements of the joint is known as 'overwelding'. There is always an excess of weld metal in a conventional fillet weld because of the convex or concave profile. Although this excess does not increase the strength it increases the effective shrinkage force. By using a deep penetration electrode, this may be overcome (*see also* Fig. 50, 51 and 52).

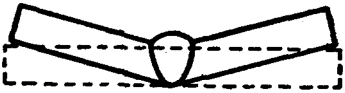


FIG. 50 DISTORTION DUE TO OVERWELDING

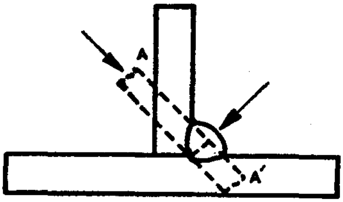


FIG. 51 EXCESS WELD METAL ABOVE THE LINE *A A'* OF CONVENTIONAL FILLET WELD

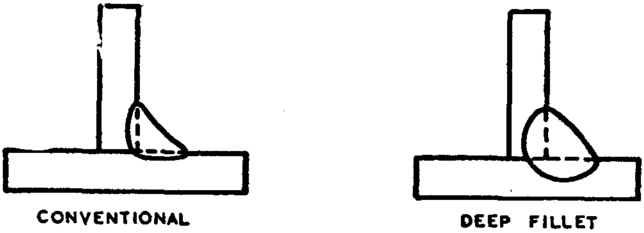
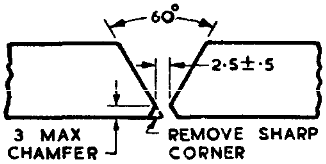
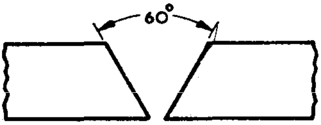


FIG. 52 DEEP PENETRATION FILLET WELD

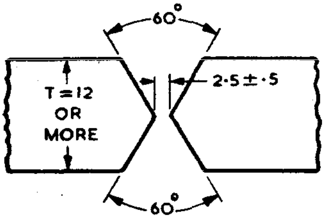
b) *Use of proper edge preparation and fit-up* — It is also possible to reduce the effective shrinkage force by correct edge preparation which will ensure proper fusion at the root of the weld with a minimum of weld metal (*see* Fig. 53).



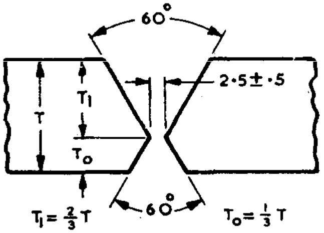
(a) RIGHT, SINGLE V-JOINT 15-20% LESS WELD METAL THAN (b)



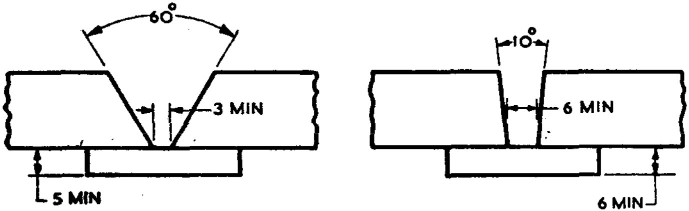
(b) WRONG, SHARP EDGES DIFFICULT TO WELD



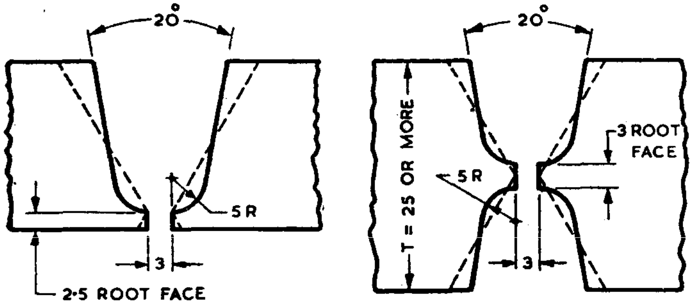
(C) DOUBLE V-JOINT TO BE WELDED DOWNHAND BOTH SIDES



(d) DOUBLE V-JOINT TO BE WELDED OVERHEAD ONE SIDE



(e) USE OF BACKING BAR ALL WELDING FROM ONE SIDE



(f) U PREPARATIONS FOR MINIMUM DISTORTION AND MAXIMUM ECONOMY IN WELD METAL, V SHOWN DOTTED FOR COMPARISON

All dimensions in millimetres.

Fig. 53 Preparation of Plates for Butt Welding

c) *Use of few passes* — Use of fewer passes with large electrodes reduces distortion in the lateral direction (*see* Fig. 54).

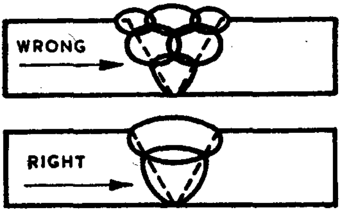


Fig. 54 Comparison of Passes of Weld

d) *Location of welds near the neutral axis* — Another means of reducing the effective shrinkage force in a tee-joint is to place the weld as close as possible to the neutral axis by using the deep fillet method. This will reduce the leverage of pulling the plates out of alignment (*see* Fig. 55).

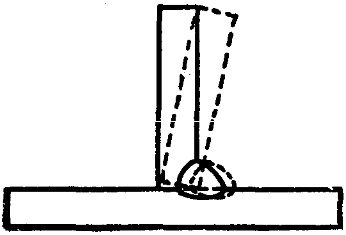
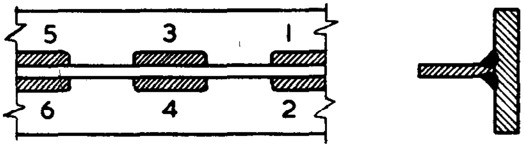


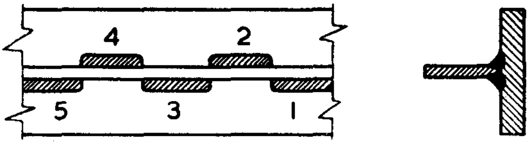
Fig. 55 Location of Welds Near the Neutral Axis

e) *Use of intermittent welds* — To further reduce effective shrinkage force by minimizing the amount of weld metal, intermittent welds as shown in Fig. 56 may be used in many cases instead of continuous welds. It is often possible to use only about two-thirds of the weld metal to obtain the strength required. Also, use of intermittent welds distributes the heat more widely throughout the structure. It is possible to use this method only on fillet welds.

f) *Use of 'back-step' welding method* — If the job requires a continuous weld, it is still possible to reduce the effective shrinkage force by the 'back-step' technique. Here the general direction of welding progression is, say from left to right, but each bead is deposited from right to left as shown in Fig. 57. In this technique, the plates expand to a lesser degree with each bead, because of the locking effect of each weld.



56A Chain Intermittent Fillet Welding



56B Staggered Intermittent Fillet Welding

FIG. 56 INTERMITTENT WELDING

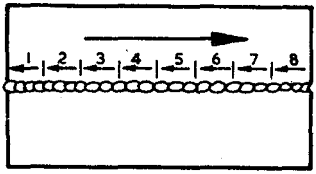


FIG. 57 BACK-STEP WELDING METHOD

g) *Welding from centre* — Welding of long joints from the centre outwards breaks up the progressive effect of a continuous weld which may produce high stresses.

h) *Use of planned wandering method* — In this method, welding starts at the centre and thereafter portions are completed on each side of the centre in turn as shown in Fig. 58.

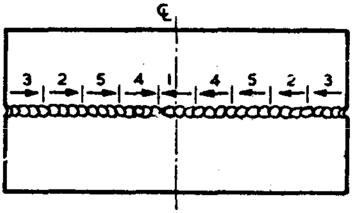
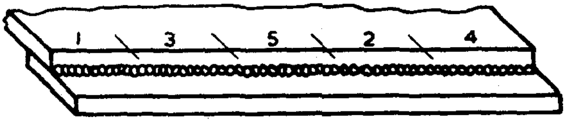
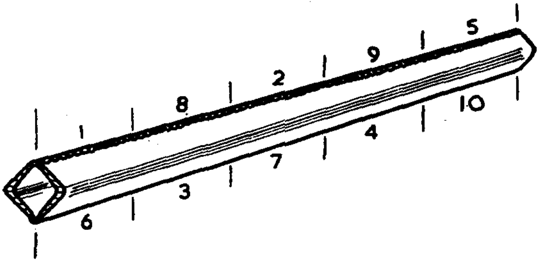


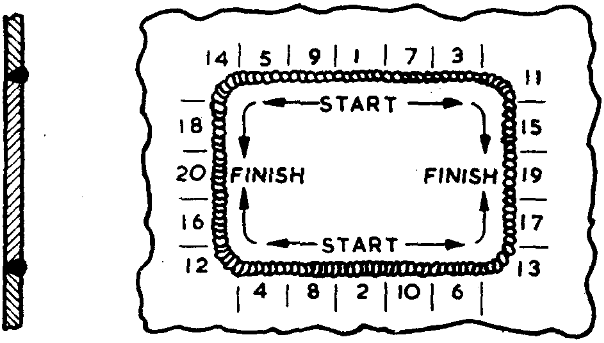
FIG. 58 PLANNED WANDERING METHOD

j) *Use of skip welding* — Skip welding will reduce locked-up stresses and warping due to more uniform distribution of heat. In this method, the weld is made not longer than 75 mm at one time (*see* Fig. 59).





AS USED WHEN FABRICATING SQUARE SECTIONS FROM ANGLES OR CHANNELS



AS USED TO MINIMIZE LOCKED UP STRESSES IN TIED JOINTS

FIG. 59 SKIP WELDING

6.5.1.2 Following methods may be used for making the shrinkage forces work to reduce distortion:

a) *Locating parts out of position* — Distortion may be allowed for by pre-setting the plates in the opposite way so that the weld pulls them to the desired shape. Tee-joint or fillet weld being made with the vertical plates out of alignment before the weld is deposited is illustrated in Fig. 60. When the weld shrinks it will pull the vertical plate to its correct 90° position.

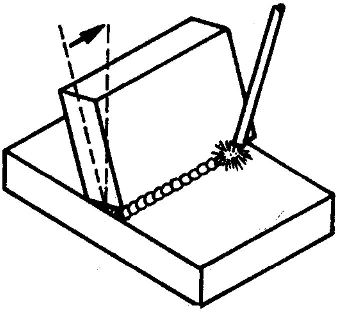


FIG. 60 ILLUSTRATION SHOWING PARTS OUT OF POSITION OF TEE-JOINT

b) *Spacing of parts to allow for shrinkage* — Correct spacing of the parts prior to welding will allow the arms to be pulled in correct position by shrinkage force of the welding as illustrated in Fig. 61, showing the trunnion arms of a long searchlight.

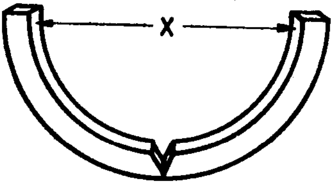


FIG. 61 SPACING OF PARTS TO ALLOW FOR SHRINKAGE

c) *Prebending* — Shrinkage force may be put to work in many cases by prebending or prespringing the parts to be welded, as shown in Fig. 62 where the counter-force exerted by the clamps overcomes most of the shrinkage tendency of the weld metal. But when the clamps are removed, there is still a slight tendency for the weld to contract, and this contraction of shrinkage force pulls the plates into exact alignment.

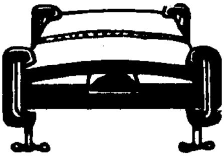


FIG. 62 PREBENDING

6.5.1.3 Balancing of one shrinkage force with another shrinkage force may be accomplished by the following methods:

a) *Use of proper welding sequence* — This places the weld metal at different points about the structure. A simple example of this is welding alternately on both sides of the neutral axis of a member in making a fillet weld. Here the pull on each side is equal and the plates remain upright (*see* Fig. 63).

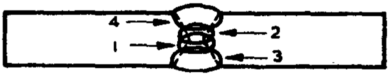


FIG. 63 BALANCING SHRINKAGE FORCE IN BUTT WELD BY WELDING ALTERNATELY ON BOTH SIDES

Another application of the above principle is when making a double-V butt weld. In this case the welds are made from each side alternately so that when a second run of weld metal shrinks it will counteract the shrinkage force of the first weld; similarly, the shrinkage force of second weld will be balanced by the shrinkage force of the third weld and so on as shown in Fig. 56.

b) *Peening* — This is light hammering of the weld metal immediately after it is deposited. By peening the bead, it is actually stretched, counteracting its tendency to contract as it cools. Peening should be used with great care, for too much peening may damage the weld metal.

c) *Divergence allowance* — As there is a tendency of the edges of plates to converge along the seam during welding, a technique which may be adopted is to diverge the plates from the point where welding commences by placing a wedge or an alignment clamp between the plates ahead of the weld; the spacing allowances being about 2 cm/m for mild steel and 4 mm/m for other ferrous metals (*see* Fig. 64).

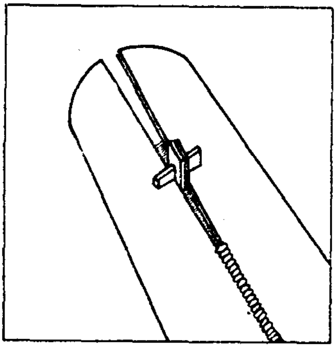


FIG. 64 DIVERGENCE ALLOWANCE

d) *Pre-heating* — Some of the metals which would normally fracture if welded in the cold state, may be satisfactorily welded by pre-heating and by subsequent controlled cooling. Sometimes local pre-heating, that is, heating only the joint and its vicinity, will overcome the tendency to cracking caused by stresses set up by welding. In Fig. 65, if the fracture in the wheel at *A* is to be repaired, the pre-heating flame should be applied at *B* to avoid cracking.

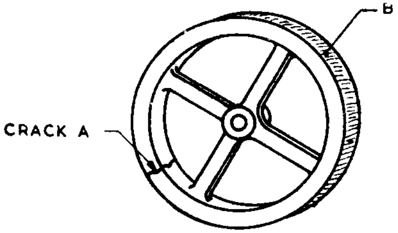


Fig. 65 Technique of Local Pre-heating

Small castings may be pre-heated by application of the blowpipe flame before commencing the weld, but larger work should be pre-heated in a gas furnace or by means of a temporary charcoal furnace. A blacksmith's forge or coke fire is not recommended, owing to the danger of sulphur from the coke entering the weld, and the concentration of heat at one spot.

e) *Jigs and fixtures* — The most important method of avoiding distortion, and one in which Rule 3 is applied to the fullest extent, is the use of clamps, jigs, or fixtures to hold the work in a rigid position during welding. By using these, the shrinkage forces of the weld are balanced with sufficient counter force of the jigs and fixtures, thus causing the weld metal itself to stretch, thereby preventing distortion (*see* Fig. 66).

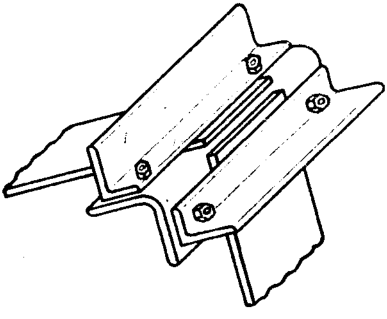


Fig. 66 Use of Jigs and Fixtures to Avoid Distortion

f) *Tack welding* — A tack weld is a short weld made prior to welding to hold the plates in perfect alignment and with uniform root gap. Tack welds are made at regular intervals along the joints with high current to obtain proper penetration (*see* Fig. 67). They are necessary in all cases where the plates are not held by a fixture.

When welding mild steel, the maximum pitch (P) of the tack weld is given by the formula:

$P = 100\text{ mm} + 16\,T$, and

$L = 3T$

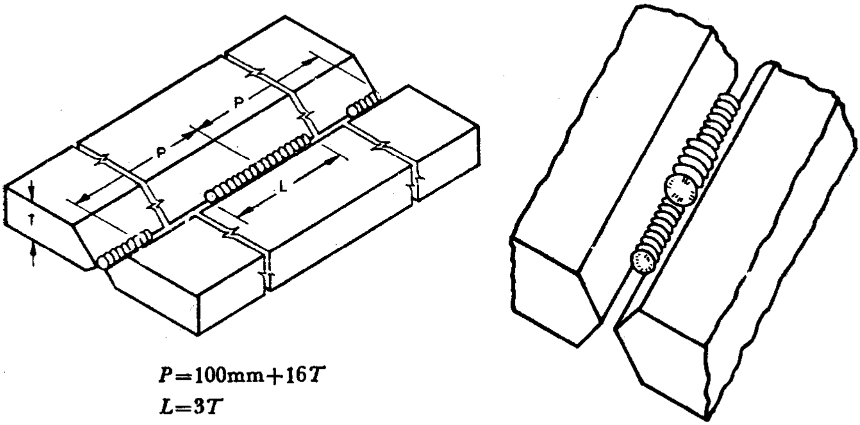
where

T = plate thickness in mm, and

L = length of each tack in mm.

Thus for a 10-mm plate, the tacks will be at 260 mm pitch and each tack will be 30 mm long.

On very thick plates, where strong tacks are required, the tack weld should be made in two runs, the top bead being shorter than the bottom one with the object of obtaining better fusion when the main weld is made. Tacks should be deslagged before the main weld is made.



$P = 100\text{mm} + 16T$

$L = 3T$

67A Tack Weld in Single Layer

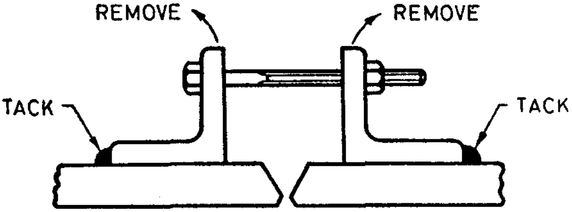
67B Tack Weld in Two Layers

NOTE — Top layer is shorter in length than bottom layer.

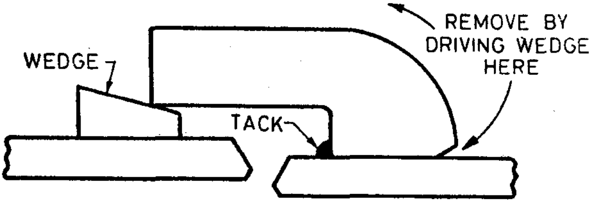
FIG. 67 TACK WELDING TECHNIQUE

It is emphasized that tack welds should be strong enough to hold the plates in position. If a tack weld gives way, it should be chipped out and rewelded. It is not permissible to weld over the top of a cracked tack weld as this would leave a fault in the weld. Tack welding for fillet welds is carried out in the same manner as for butt welds; only the pitch of the tack in the case of fillet welds will be about twice that used for the butt welds.

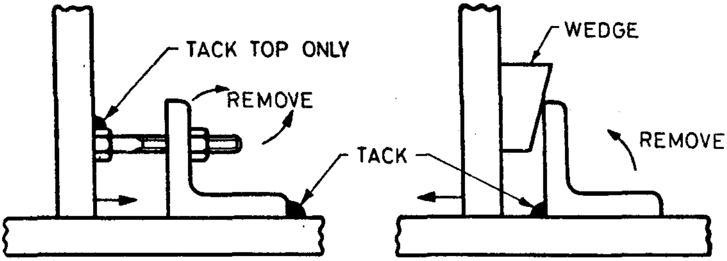
Tack welding is also applied to small welds on erection cleats and aids used during assembly. These welds should be so made that they may be removed easily afterwards. Tack welding on erection as an aid to assembly is shown in Fig. 68.



68A Closing a Butt Weld



68B Lining up a Butt Weld



68C Pulling into Position

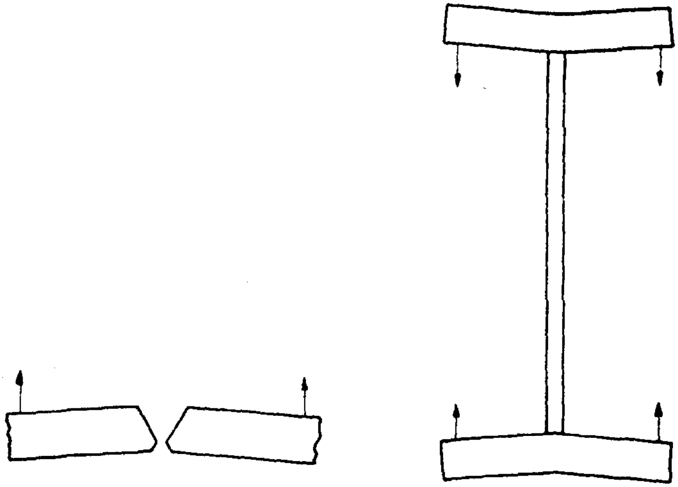
68D Putting into Position

FIG. 68 TACK WELDING ERECTION CLEATS AND AIDS TO ASSEMBLY

6.5.2 *Control of Residual Stresses* — The general rules for the control of residual stresses are given below:

a) In making a weld of specified size, a few large runs are better than a number of small runs, as shown earlier in Fig. 49.

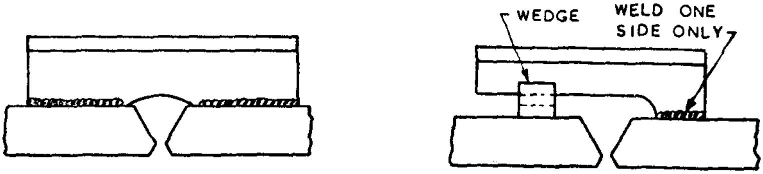
b) Distortion should be allowed to occur only where it is not objectionable. For example *see* Fig. 69.



SINGLE—V BUTT PRE-SET TO STRAIGHTEN OUT ON COMPLETION OF WELDING

FLANGES OF PLATE GIRDER PRE-SET TO STRAIGHTEN OUT WHEN WELDED TO WEB

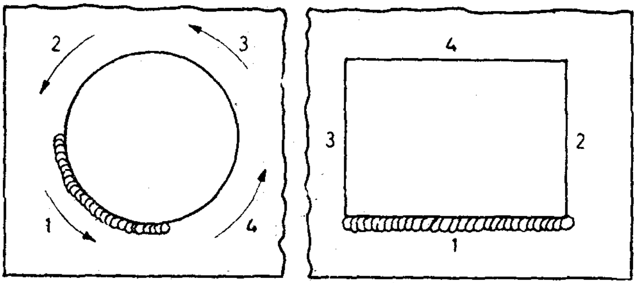
69A Allowing for Distortion by Pre-setting



WRONG. WELDS BOTH SIDES RESTRAIN CONTRACTION OF BUTT

RIGHT. WEDGE HOLDS PLATE IN POSITION BUT DOES NOT RESTRAIN CONTRACTION

69B Use of Wedge to Hold Joint in Line and at the Same Time Allow Contraction



69C Welding in Patches (Allow to Cool Between Each Stage)

Fig. 69 Technique of Controlling Residual Stresses

c) Where it is not possible to remove a member, welds should be made in stages and each weld should be allowed to cool before making the next one. An example of this is illustrated in Fig. 69C. It is extremely difficult to make this weld without a crack appearing, because during welding the circular plate becomes much hotter than the plate surrounding the hole and on cooling, the weld is subject to stresses in all directions. Here each individual run, particularly the first, should be heavy so that it is strong enough to resist the contractional pull on the weld (*see* Fig. 69).

6.6 Technique of Edge Preparation for Butt Welding Unequal Thicknesses

In butt welding plates differing in thicknesses by not more than 20 percent a single V-weld with 60° included angle is used; the required slope may be obtained in the weld itself (*see* Fig. 70).

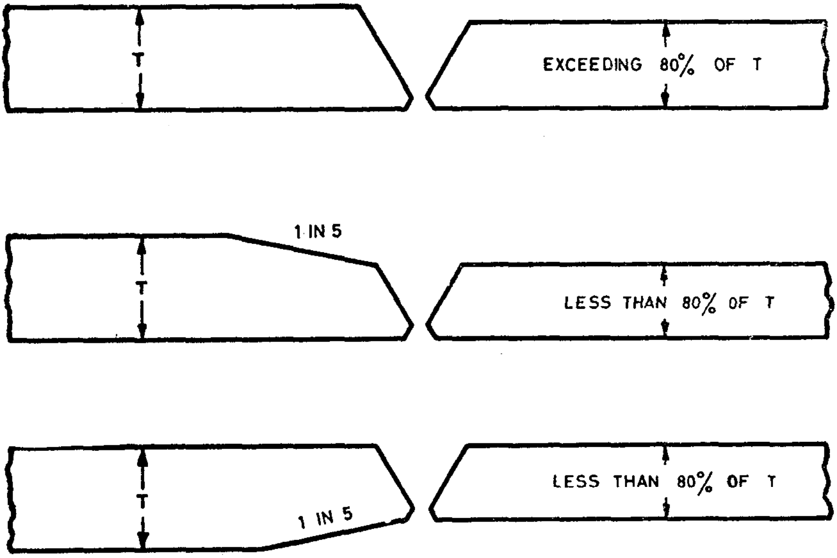


FIG. 70 EDGE PREPARATION FOR BUTT WELDING UNEQUAL THICKNESSES

When the thickness of plates being butt welded differs by more than 20 percent, it is usual to chamfer the thicker plate to equal the thinner plates, the slope of the chamfer being 1 in 5 as shown in Fig. 70. This procedure is often used in plate girders.

6.7 Technique of Heat-Treatment Before and After Welding

As already explained welding introduces stresses and also causes changes in the structure of the metal in and around the welded joint. In a majority of cases, these effects are insignificant and may, therefore, be ignored. However, there are occasions where some form of heat-treatment of the weld joint or the entire workpiece is necessary.

Heat-treatment consists of pre-heating or post-heating or both.

6.7.1 *Pre-heating* — The purpose of pre-heating is to prevent rapid quenching effect of the weld metal by the surrounding cold mass of the parent metal. Generally, pre-heating does not require rigid control of temperatures and may be used when welding:

a) heavy mild steel sections;

b) medium carbon and low alloy high tensile steels;

c) aluminium, stainless steel, copper and copper alloys; and

d) cast iron.

The pre-heating temperature is usually low and is well below the critical temperature (*see* Section 7). The temperature may be detected in a number of ways, for example, by the appearance of temper colours on a clean surface as given in Table VI.

TABLE VI TEMPER COLOURS FOR CARBON STEEL

TEMPERATURE °C	COLOUR
220	Light straw
230	Straw to dark straw
240	Golden yellow
255	Yellowish brown
265	Reddish brown, dappled purple
280	Purple
290	Violet
305	Blue
320	Dark Blue

There are three forms of pre-heating, namely:

a) local pre-heating to retard the rate of cooling of the weld;

b) general pre-heating to release internal locked-up stresses and to retard cooling; and

c) indirect pre-heating, which is often useful if used with caution for expanding an associate part of the casting in order to reduce the contractional stresses caused by welding.

Small workpieces may be pre-heated with a blowlamp or an oxy-acetylene torch, but larger workpieces should be pre-heated in a gas furnace or in a charcoal furnace. A simple furnace for pre-heating and annealing may be built of bricks as shown in Fig. 71.

Care should be taken to heat the workpiece evenly and uniformly. After welding, the workpiece should be allowed to cool slowly away from draughts.

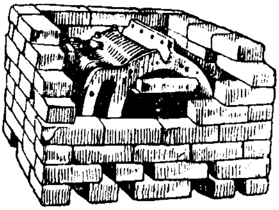


FIG. 71 PRE-HEATING AND ANNEALING FURNACE

6.7.2 *Post-heating* — Another method of retarding the rate of cooling of a welded joint is by the application of heat immediately after welding. The essential feature of this treatment is to slow down the cooling rate within a certain temperature range. In the case of plain carbon steels, this range is confined to 300° to 100°C. Post-heating covers normalizing, annealing, stress relieving and such other operations described below:

a) *Normalizing* involves heating the workpiece to the appropriate normalizing temperature (which is above the critical temperature) and subsequently cooling it in air. This operation refines the structure of the welded joint. However, this process has been found to give rise to new residual stresses and is not normally recommended.

b) *Annealing* involves heating the workpiece above the critical temperature and subsequent cooling at a very slow rate usually in a furnace. Heating should be done as slowly and uniformly as possible. The annealing temperatures differ for different metals and alloys. The cooling period varies from a few hours to several days depending upon the size and shape of the workpiece. When it is necessary to machine parts to close tolerances they are usually annealed after welding.

   Metals having properties derived by special heat-treatment such as hardening, tempering, etc, should be softened prior to welding by annealing, welded and then re-hardened or otherwise treated to restore them to their original state.

c) *Stress-relieving* is a treatment resorted to bring about improvement in mechanical properties by relieving internal stresses. It is an accepted treatment for welded pressure vessels and boilers. Also parts which are subject to high dynamic stresses in service call for this treatment, for example, moving parts of machinery. It is carried out by uniformly heating the workpiece to a temperature of 600° to 650°C which is much below the critical temperature and cooling it slowly and evenly to the room temperature. The workpiece is maintained at this temperature for a period which is dependent on the thickness of the workpiece. This is usually one hour for every 25 mm thickness. Table VII gives typical recommended stress-relief temperatures for various types of steels.

TABLE VII TYPICAL STRESS-RELIEF HEAT-TREATMENTS

MATERIAL	HOLDING TEMPERATURE °C	SOAKING TIME IN HOURS
Carbon steel	600 to 675	1
Carbon—1/2% Mo (0·20% C)	600 „ 675	2
Carbon—1/2% Mo (0·35% *Max*, C)	675 „ 780	2
2% Cr—1/2% Mo	720 „ 750	2
2¼% Cr—1% Mo	730 „ 780	3
5% Cr—1/2% Mo	730 „ 780	3
12% or 16% Cr	775 „ 800	2
18% Cr—8% Ni	650 „ 815	4—2

NOTE 1 — Heating rates are generally less than 200°C per hour with less than 90°C per hour being used for austenitic steels and usually for chrome-molybdenum and straight chrome steels. Cooling rates are generally not more than 90°C per hour with lower values for alloy steels.

NOTE 2 — Soaking time given in this table is for 25 mm thickness of material.

6.8 Arc Blow and Its Remedy

In DC welding the arc stream often tends to deviate from its intended path. This action of the arc is known as arc blow.

During the welding process the current flows through the electrode, arc stream and the base metal. This current sets up magnetic fields around the electrode, the arc stream and the base metal (*see* Fig. 72). The combination of the action of these magnetic fields or fluxes on the arc stream may, under certain conditions, pull the arc stream out of its intended path.

6.8.1 When an arc blow occurs, the arc becomes wild and uncontrollable. Arc blow may generally be reduced greatly by the following measures:

a) By welding towards a heavy tack or towards a weld already made;

b) By using back-stepping on long welds;

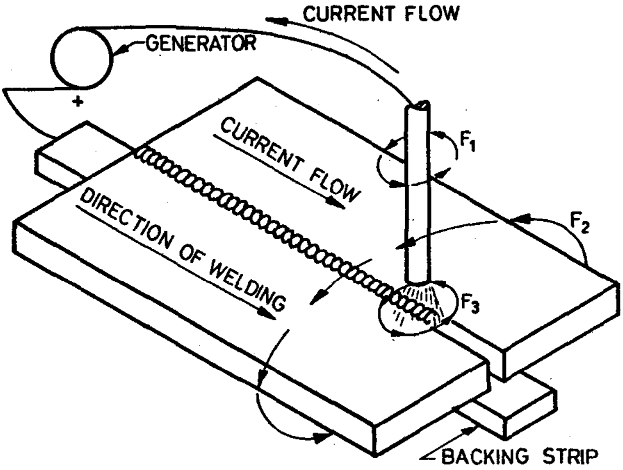


Fig. 72 Planes in Which Magnetic Fields Are Set Up

c) By placing ground connection as far as possible from the joint being welded;

d) By holding a short arc, almost touching the plate, directing the tip of the electrode in the direction opposite to that of arc blow, so that the arc force will counteract the arc blow;

e) By reversing the polarity of the electrode and work connection, thus reversing the direction of current flow;

f) By winding the welding cable 2/3 times round the workpiece;

g) By shifting the position of the clamp which holds the return lead to the workpiece in order to provide a different path through the work for the current; and

h) By using two earth leads, one at each end.

In most cases, the arc blow may be corrected by experimenting on the above lines, but occasionally it may be very troublesome and difficult to eliminate.

Arc blow does not exist in AC arc welding. Whenever it is not possible to accomplish welding because of arc blow, AC welding may be used.

6.9 Summary of Recommendations

a) Every endeavour should be made to stick to the recommended welding procedure and technique depending on the nature of work.

b) All surfaces to be welded should be thoroughly clean and free from scale, paint, grease or dirt.

c) Adequate steps should be taken to maintain the correct current setting, angle of electrode, speed of travel, arc length, and polarity of the electrode in the case of DC.

d) As large an electrode as possible should be used.

e) The crater or the depression at the end of a weld should be avoided by welding back over the last 6 to 12 mm of weld and the electrode should be withdrawn from the side instead of vertically.

f) Deposited weld metal should have a smooth and regular appearance, the ripples and the width of bead being uniform.

g) Welding should be done at a uniform speed so that there is proper fusion at the sides of the joint with adequate penetration of the weld metal.

h) Butt weld should be flush without excessive build up.

j) Fillet welds should have equal leg lengths.

k) Dry electrodes should be used.

SECTION 7

WELDING METALLURGY

7.1 General

Welding is not merely a trade requiring only skilful manipulation of the hands, but a highly specialized process, demanding on the part of the operator a sound knowledge of the behaviour and properties of metals and alloys when heated and cooled. The welder should have a knowledge of metallurgy in general and welding metallurgy in particular. It is this knowledge which will enable him to carry out welding successfully on different types of plain carbon and alloy steels, particularly on the complex alloy steels which are being developed these days to meet severe service conditions.

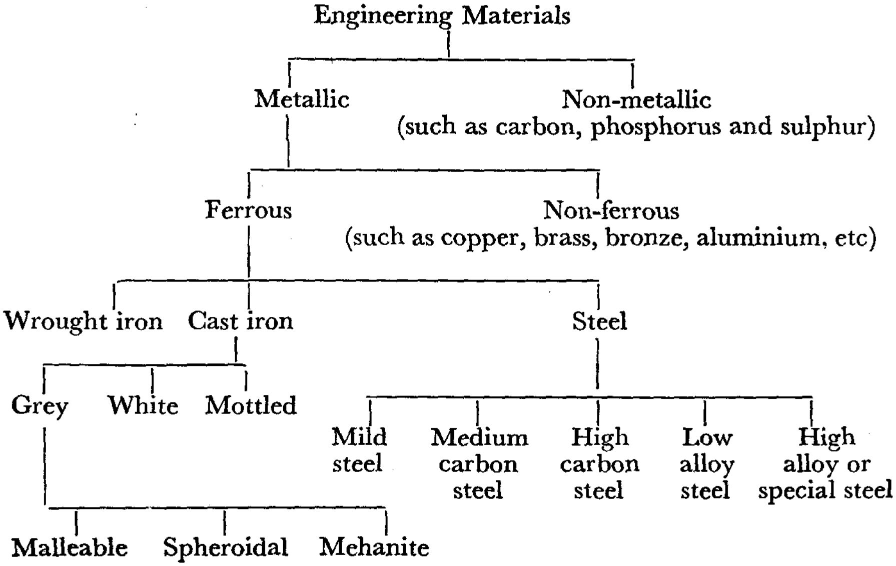
In this Section, the materials which the welder normally comes across have been dealt with. Also, the various metallurgical factors which influence the properties of the weld and the parent metal during and after welding have been explained. The procedure to be adopted in making sound welds with different materials have been described.

7.2 Classification of Materials

The materials used by engineers may be classified as:

a) metallic, and
b) non-metallic.

Metallic materials may again be broadly divided into two groups, namely, ferrous and non-ferrous. The ferrous metals may be further subdivided as follows:



7.2.1 *Ferrous Materials* — These have iron as their base. Examples are cast iron, wrought iron, mild steel, carbon steel, alloy steel, etc.

All ferrous materials are derived from pig iron which is the raw material obtained by the reduction of iron ore in the blast furnace. These are essentially alloys of iron and carbon containing manganese, silicon, etc, and incidental impurities, such as sulphur, phosphorus, etc. All these have a direct bearing on the physical properties of the metals and also affect their weldability.

Alloys of iron and carbon containing up to 1·2 percent carbon are generally known as steels and those which contain more than 1·2 percent carbon are generally known as cast irons. There is, however, no clear cut line of demarcation between the two.

Steels used in industries may be divided into two groups, namely, plain carbon steels and alloy steels. The properties of carbon steels depend essentially on their carbon content. The properties of alloy steels depend upon the carbon content, the amount of one or more alloying elements, such as nickel, chromium, molybdenum, vanadium, tungsten, etc, and the presence of increased percentages of manganese or silicon.

In steels, the presence of alloying elements in small quantities improves in general their mechanical properties, such as strength, toughness, hardness, etc. Certain special properties, such as resistance to heat, corrosion, shock or wear may be conferred on steels by the addition of suitable alloying elements in sufficiently large quantities. The alloy steels, therefore, are further divided into:

a) low alloy steels which contain alloying elements in small amounts to improve their general mechanical properties, and

b) high alloy steels or special alloy steels which contain suitable alloying elements in large quantities to impart certain special properties to the steels to form austenitic, corrosion and heat-resisting steels, high-speed cutting steels, air-hardening steels, etc.

7.2.2 *Non-ferrous Materials* — These are metals other than iron as base but iron may be present in them as an incidental impurity. Examples are copper, brass, bronze, aluminium, etc.

7.3 Identification of Metals

It is essential for the welder to be familiar with some rough and ready method of identifying metals in order to distinguish one from the other. There are various kinds of distinguishing tests which help the operator to recognize the various grades of iron and steel. Of all these tests, the spark test is the most useful in the workshop. The spark test is done by holding tightly a sample of the metal on a grinding wheel and then observing the shape. colour and length of the streaks and sparks produced (*see* Fig. 73).

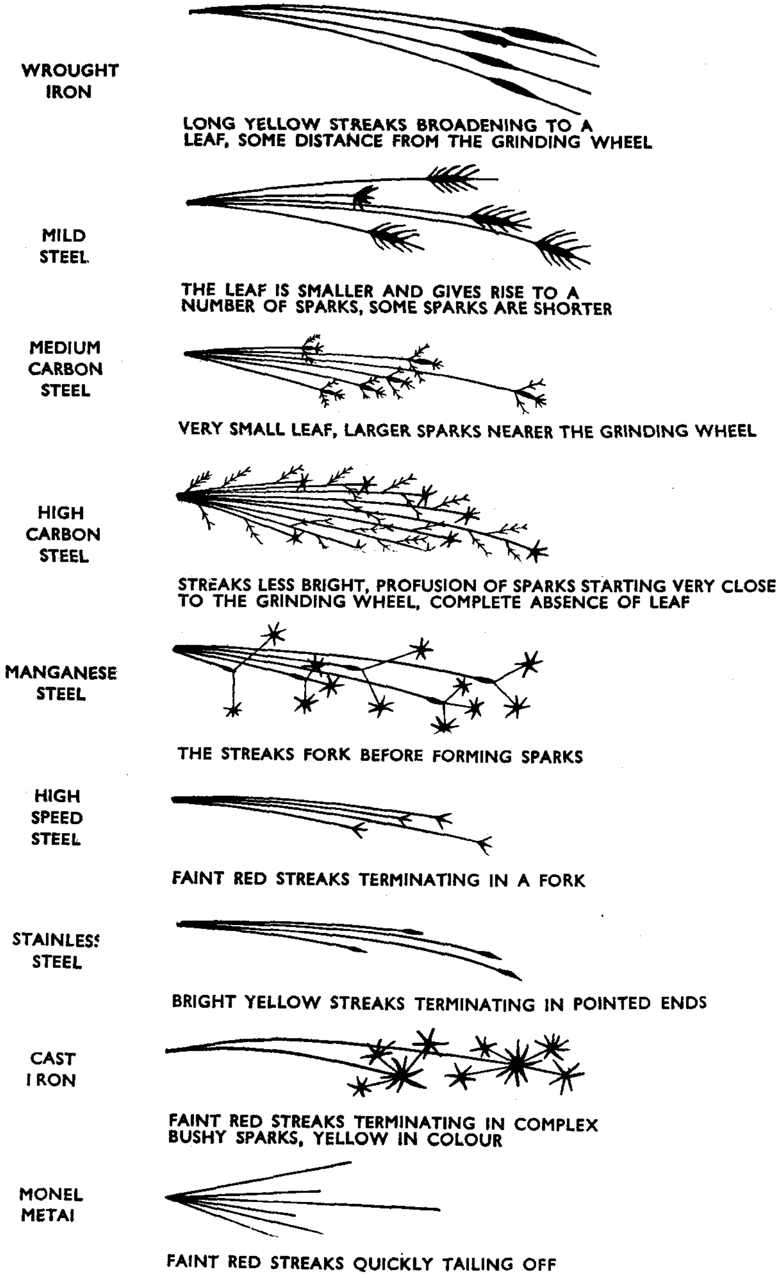

WROUGHT IRON
LONG YELLOW STREAKS BROADENING TO A LEAF, SOME DISTANCE FROM THE GRINDING WHEEL
MILD STEEL
THE LEAF IS SMALLER AND GIVES RISE TO A NUMBER OF SPARKS, SOME SPARKS ARE SHORTER
MEDIUM CARBON STEEL
VERY SMALL LEAF, LARGER SPARKS NEARER THE GRINDING WHEEL
HIGH CARBON STEEL
STREAKS LESS BRIGHT, PROFUSION OF SPARKS STARTING VERY CLOSE TO THE GRINDING WHEEL, COMPLETE ABSENCE OF LEAF
MANGANESE STEEL
THE STREAKS FORK BEFORE FORMING SPARKS
HIGH SPEED STEEL
FAINT RED STREAKS TERMINATING IN A FORK
STAINLESS STEEL
BRIGHT YELLOW STREAKS TERMINATING IN POINTED ENDS
CAST IRON
FAINT RED STREAKS TERMINATING IN COMPLEX BUSHY SPARKS, YELLOW IN COLOUR
MONEL METAL
FAINT RED STREAKS QUICKLY TAILING OFF

Fig. 73 Spark Test

7.4 Metallurgy of Steel

The metallurgy of welding steel is easily understood only when one has at least an elementary knowledge of:

a) the changes that occur in the structure of pure iron with rise in temperature;

b) the effect of addition of carbon on the structural changes that occur in iron with rise in temperature;

c) the changes that occur in the structure and constitution of iron-carbon alloys:

   1) with rise in temperature, and

   2) with different rates of cooling from temperatures as met with during welding;

d) the mechanical properties of steels that have been cooled at different rates from temperatures as met with during welding;

e) the effect of increase in carbon content on the mechanical properties of steels that are cooled very rapidly from high temperatures as met with during welding; and

f) the effect of dissolved hydrogen in steel.

Each one of the above is dealt in an elementary way in **7.4.1** to **7.4.6.**

7.4.1 Pure iron at room temperature exists in a particular crystallographic form called 'α' (Alpha) iron. When 'α' (Alpha) iron is heated to a temperature above 910°C, it transforms into another crystallographic form called 'γ' (Gamma) iron. This temperature at which the transformation occurs is called the 'transformation temperature'. When cooling from a temperature above 910°C, the transformation gets reversed, that is, the 'γ' (Gamma) form changes to 'α' (Alpha) form. The 'α' iron takes only a little quantity of carbon into solution, while the 'γ' iron takes up to 1·7 percent carbon into solution.

7.4.2 The effect of addition of carbon to pure iron is to lower the transformation temperature from 910° to 725°C as the carbon content increases from 0 to 0·83 percent. In steels containing more than 0·83 percent carbon, the transformation from 'α' (Alpha) to 'γ' (Gamma) form on heating and from 'γ' (Gamma) to 'α' (Alpha) form on cooling occurs at about 725°C.

7.4.3 For example, when an iron-carbon alloy containing 0·3 percent carbon is cooled slowly from a temperature above 910°C to room temperature and then examined under a microscope, the structure will consist of grains of two constituents, namely, 'ferrite' and 'pearlite' (*see* Fig. 74). 'Ferrite' is 'α' (Alpha) iron with negligible quantity of carbon in solution. 'Pearlite' is made up of alternate layers of ferrite and carbide of iron (Fe_3C). This carbide is called 'cementite'. The pearlite grains have a definite carbon content which is about 0·83 percent.

When this steel is heated, the 'α' (Alpha) iron changes to 'γ' (Gamma)

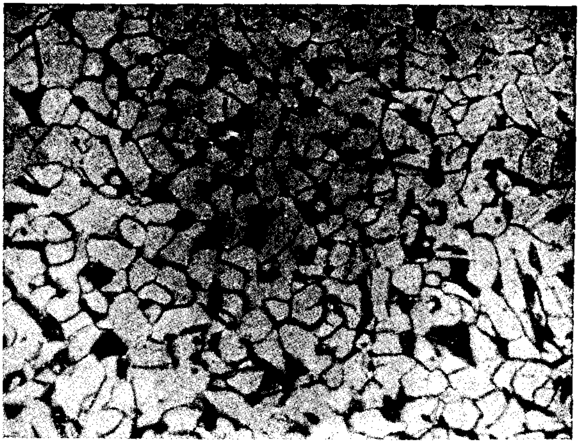


FIG. 74 FERRITE AND PEARLITE

form at the transformation temperature. As 'γ' (Gamma) iron dissolves carbon up to 1·7 percent, the resultant 'γ' (Gamma) iron will hold the entire 0·3 percent carbon in solution. This solid solution of carbon in 'γ' (Gamma) iron is called 'austenite'. So, at all temperatures above the transformation temperature, the steel will be entirely 'austenitic'. When this austenite is slowly cooled, and the transformation temperature is reached, ferrite grains begin to separate out. As ferrite contains hardly any carbon and the austenite is capable of taking in more carbon, the excess carbon goes into austenite and with the fall in temperature, the carbon content of austenite goes on increasing till it reaches 0·83 percent, which is the carbon content of pearlite. At about 725°C, this austenite suddenly changes to pearlite (*see* Fig. 75). So the structure of this steel, when slowly cooled, will consist of grains of 'ferrite' and 'pearlite' (*see* Fig. 74).

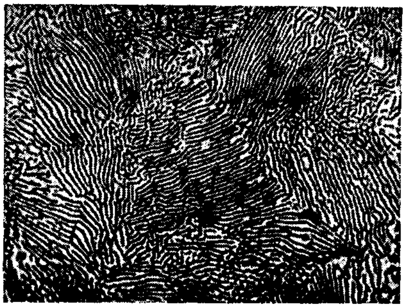


FIG. 75 PEARLITE

7.4.4 When the austenite is cooled at increasing rates, the alternate layers of ferrite and cementite constituting the pearlite become finer and finer. The effect of this is to increase the hardness of the steel so treated. When the cooling rate exceeds a particular value, a new structure entirely different from fine pearlite results. It is called 'martensite' (*see* Fig. 76) and it is the hardest constituent in steel. The steel so treated, therefore, will be very hard, brittle and less ductile.

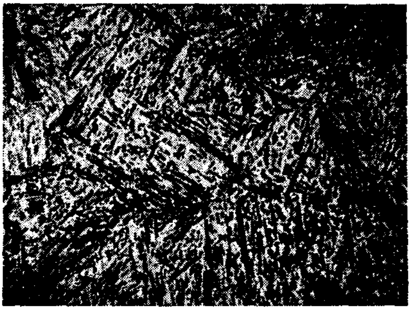


FIG. 76 MARTENSITE

7.4.5 As the carbon content in steel increases, a lesser rate of cooling is adequate to produce the hard martensitic constituent. In other words, the tendency for the steel to become hard and brittle for a given rate of cooling increases with the carbon content. Ordinary structural mild steel has sufficiently low carbon to prevent hardening under any condition of cooling. But, the medium and high carbon steels contain enough carbon to render the parent material extremely hard and brittle when cooled from welding temperature at ordinary rates of cooling as met with in practice.

Under the usual conditions in welding shop, the rate of cooling is not only dependent on the difference in temperature between welding temperature and the room temperature, but also on the mass of the parent metal which conducts the heat away from the weld metal and the heat-affected parent metal. So, in thicker sections, the rate of cooling is high, that is, the tendency for the formation of hard constituent is increased.

7.4.6 Cracks formed in the parent metal underneath the weld bead (under-bead cracking) and minute cracks in the weld metal are attributed to the absorption of hydrogen by the weld metal at high temperature and diffusion of the same to the heat-affected zone in the parent metal and its subsequent release on cooling. The hydrogen comes from the organic materials and the moisture present in the coating of ordinary mild steel electrodes. During welding, this gas is absorbed by the weld metal. At high temperatures, the weld metal will be in the austenitic condition 'γ' (Gamma) form, which takes into solution hydrogen to a large extent. But the 'α' (Alpha) form does not take into solution hydrogen to that extent. Further, the solubility of hydrogen also decreases with fall in temperature. If the weld metal is cooled slowly, the dissolved hydrogen escapes by diffusion without producing cracks in the weld metal. If the weld metal is cooled very rapidly, excess hydrogen will be held forcibly in solution and will not have sufficient time to escape. The entrapped hydrogen will exert heavy pressure and will escape causing minute cracks in the weld metal or in the parent metal next to the weld.

This defect may be overcome by allowing the weld metal to cool very slowly thus allowing the hydrogen to escape or by eliminating hydrogen-bearing compounds in the coating of the electrode. Such electrodes are called the low-hydrogen electrodes.

7.5 Weldability

Weldability may be defined as a combined property of parent metal and filler metal or electrode, the measure of which is the capacity to produce a crack-free and mechanically satisfactory joint. In other words, it is the capacity of a metal to be welded under the fabrication conditions imposed into a specific, suitably designed structure and to perform satisfactorily the intended service. This means, that if a particular metal is to have good weldability, it should be welded readily so as to perform its functions satisfactorily in the fabricated structure; it should not require expensive or complicated and exacting procedures in order to produce sound joints.

In order to determine the weldability of a metal, it is essential to know its mechanical properties as determined by its chemical composition, and the effects of welding on its mechanical properties. In the following paragraphs, the chemical composition and salient points, in so far as the welding of steels, cast iron and non-ferrous metals is concerned, have been explained.

7.6 Welding of Steels

7.6.1 *Mild Steel* — Steels which have a low carbon content are called mild steel. Mild steel is essentially an alloy of iron and carbon containing not more than 0·30 percent carbon, the usual percentage being between 0·10 percent and 0·20 percent. Welding quality mild steel has the following approximate composition:

Constituent	*Percent*
Carbon, *Max*	0·25
Manganese, *Max*	0·8
Sulphur, *Max*	0·05
Phosphorus, *Max*	0·05
Silicon, *Max*	0·25
Iron	Remainder

Mild steel has a low carbon content which prevents its hardening under any condition of cooling from high temperatures. Because of its lower carbon content, mild steel may be welded without pre-heating in comparatively thicker sections.

7.6.2 *Medium Carbon Steels* — Medium carbon steels contain carbon from

0·3 to 0·6 percent, other elements being the same as in the case of mild steel. Medium carbon steels form a hard and brittle zone next to the weld metal when rapidly cooled from the welding temperature. This heat-affected zone may develop cracks under restraint. In order to overcome this tendency, it is advisable to lower the rate of cooling by pre-heating the workpiece to between 180°C and 350°C depending upon the carbon content and thickness of the workpiece.

There is also a tendency for the weld metal to pick up carbon from the parent metal and this increases the tendency of the weld metal to become hard and brittle when cooled rapidly. As the line of maximum stress in the weld is often longitudinal through the centre of the weld, there is a tendency for the crack to occur along this plane. This may generally be overcome by pre-heating the workpiece.

Another difficulty encountered in welding medium carbon steels is the formation of under-bead cracks. As explained earlier, this is due to the absorption of hydrogen by the weld metal in its molten state from the electrode coating and its subsequent release on solidification of the metal. This may be overcome by the use of low-hydrogen electrodes.

For complicated shapes or parts having a long length of welding, it is desirable to stress relieve the welded parts at about 600°C.

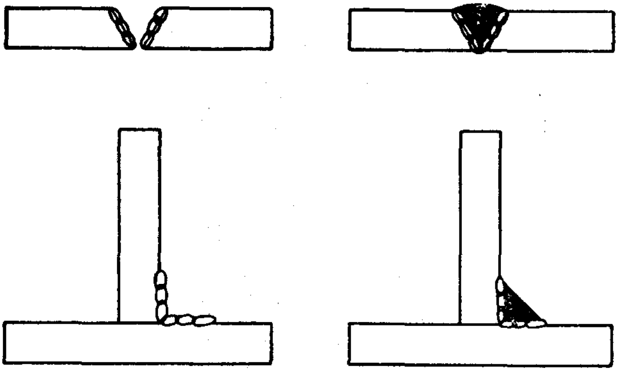
7.6.3 *High Carbon Steels* — High carbon steels contain carbon from 0·6 to 1·2 percent, other elements being the same as in the case of mild steel. These steels are not normally welded as they are usually in the form of tools and are carefully heat-treated. If they are welded and the weld metal is of a different composition, it does not attain the same hardness as the original steel during subsequent heat-treatment. The effect of the cooling rate from the welding temperature is more pronounced owing to the high carbon content and cracking is more likely to occur as the entire weld zone will be extremely brittle.

When it is necessary to weld such a steel, it should be welded using a low-hydrogen or austenitic electrode after pre-heating it to about 350°C and then stress relieving it at about 600°C immediately after welding.

Another method of welding high carbon steels is to 'butter' the surfaces to be welded before joining them (*see* Fig. 77).

In this method, the buttering layer picks up some carbon but as it is not highly stressed on cooling, it does not usually crack. The carbon content of the buttering layer is much less than that of the parent plate, so that, when the two coated surfaces are joined by a final run of weld metal, the carbon pick-up is very much reduced and the joining run does not crack. The joining run should be made while the work is still warm after deposition of the buttering runs.

7.6.4 *Low Alloy Steels* — Low alloy steels are very large in number and varied in their alloy composition depending upon the properties expected of them. For example, steel containing 0·5 percent molybdenum is used in



NOTE — Joining runs are not applied direct to the carbon steel but are applied on top of the 'buttering' runs.

FIG. 77 WELDING HIGH CARBON STEELS BY 'BUTTERING' METHOD

super-heated steam plants for superheater tubing, pipe valves, flanges and fittings, and in pressure vessels, where resistance to creep at higher temperature is necessary. Chromium-molybdenum steels, particularly 5 percent Cr—0·5 percent Mo alloy steel, are used, for example, in the petroleum oil industry because of their good metallurgical stability and resistance to attack by sulphur compounds at high temperatures. They are also resistant to attack by hydrogen at the pressures and temperatures encountered in some of the more recent refining processes. High tensile low alloy steels containing nickel, chromium and molybdenum are used in the manufacture of armoured vehicles. High tensile low alloy steels of weldable quality have been developed in recent years and in any welded structures, these should be used in preference to other low alloy steels which though having the same physical properties do not have the same degree of weldability.

The difficulties encountered in welding low alloy steels are practically similar to those met with in the welding of medium carbon or high carbon steels, as the effect of the addition of various alloying elements may be considered as equivalent to increasing the carbon content in so far as its behaviour while cooling from the welding temperature to the room temperature is concerned, that is, the susceptibility to cracking in the heat-affected zone of the parent metal, under-bead cracking and hardening of weld metal due to alloy pick-up from the parent metal.

Successful welding of low alloy steels may be achieved in most cases by paying sufficient attention to the procedure used in welding. One or more of the following precautions, as may be necessary, should be taken when welding low alloy steels:

a) Pre-heating of the parts will decrease the cooling rate after welding and will minimize the amount of martensite formation and thus the susceptibility to cracking in the heat-affected zone.

b) When using a mild steel electrode, the admixture of the parent metal and the weld metal should be kept to a minimum by using electrodes giving a low penetration and a convex bead.

c) The use of a low-hydrogen (basic) electrode will greatly reduce the tendency to crack formation due to hydrogen.

d) When certain special properties such as resistance to atmospheric corrosion are required to be retained, electrodes of chemical composition similar to the parent metal preferably with low-hydrogen (basic) coating should be used.

e) Where admixture of the weld metal with the base metal will not lead to undue hardening or cracking of the weld bead, as large a weld as possible should be deposited. By so doing the weld section is increased. This would help in resisting the stresses due to contraction thus avoiding cracks which might result if thinner weld sections are used.

f) All the precautions for the control of distortion as given in Section 6 should be taken so that the weld is subjected to as few stresses as possible during cooling.

g) Correct and consistent joint fit-up will greatly help to reduce the possibility of cracking.

h) A simple form of heating with subsequent cooling, which will prolong the time taken to cool through the range 200°C to 400°C, will be beneficial. This treatment would incidently help in relieving the stresses due to welding and also in improving the mechanical properties of the weld zone by tempering the martensite formed, if any, during cooling.

7.6.5 *High Alloy or Special Steels* — High alloy or special steels are used when certain specific properties such as resistance to heat, corrosion, wear, shock, etc, are required in their service. There are a number of special steels developed but not all of them are weldable. The main steels in the weldable group are the austenitic manganese steels and nickel-chrome corrosion and heat-resistant steels.

When these steels are to be welded, the electrodes to be used should give a weld deposit of similar chemical composition to the parent metal so that the special properties are retained by the weld deposit.

Austenitic manganese steels contain between 12 to 14 percent manganese and are used where resistance to repeated impact or battering and wear is required, as in the case of rock crusher jaws. Such steels work-harden on their outer surface under repeated impacts and still retain their toughness due to a backing of the softer, tougher metal inside. In these steels, it is not possible completely to prevent the change from the austenitic to the martensitic condition during welding but the extent of this change should be kept to a minimum by keeping the temperature during welding as low as practicable.

It is always preferable to use a current as near as possible to the lower limit of amperage recommended by the manufacturer.

When welding manganese steels, an electrode giving a weld deposit of a similar chemical composition should be used but when welding manganese steel or joining manganese steel to mild steel or stainless steel, a modified electrode based on 18/8 austenitic composition (18 percent chromium, 8 percent nickel) should be used. Electrodes giving a deposit of 12 percent austenitic manganese steel are sometimes alloyed with three to four percent nickel (as also the base metal) to reduce the tendency of the original austenitic structure to change to brittle martensitic structure after welding. When preparing the job for building up, the surface should be cleaned and all surface cracks removed by grinding as this steel hardens rapidly under cold work. Filing or chipping should not be done.

The most widely used corrosion resisting steel in industry today is the 18/8 chromium nickel austenitic steel. It is popularly known as 'Stainless Steel'. This steel is austenitic in character and is not subject to hardening by heat-treatment. Steels containing higher percentage of chromium and nickel, such as 25/20 and 25/12 chromium nickel steels are known as heat-resisting steels.

When welding corrosion and heat-resisting steels, electrodes giving deposits similar in chemical composition to the parent metal should be used. Where welding is carried out with DC current, a low-hydrogen type stainless steel electrode is preferred. Where welding is carried out with AC current, a rutile type electrode is preferred due to easier welding characteristics. Where welded components are expected to face corrosive conditions in service, the base material as well as the weld deposits should be very low in carbon, preferably below 0·1 percent carbon and in addition, be stabilized with titanium or columbium. Otherwise, a black corroded line of carbide precipitation, called 'intercrystalline corrosion' appears parallel to the weld (*see* Fig. 78). This is commonly known as 'weld decay'.

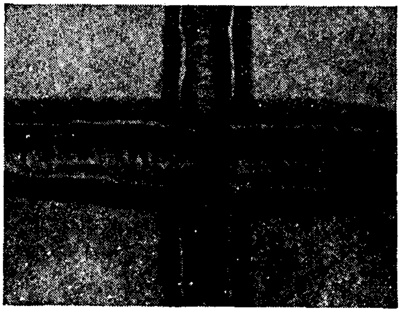


FIG. 78 INTERCRYSTALLINE CORROSION IN UNSTABILIZED 18/8 STEEL

7.7 Welding of Grey Cast Iron

It is not possible to fabricate cast iron like steel. Cast iron is cast into desired shapes by remelting pig iron along with scrap iron. It is relatively soft but brittle and has a low tensile strength. It is generally used where tensile strength is of little importance.

Cast iron is a complex alloy of six or more elements. Its composition is approximately as follows:

Constituent	*Percent*
Iron	94 to 98
Carbon	2·0 to 4·0
Silicon	1 to 3
Sulphur	0·04 to 0·10
Phosphorus	0·4 to 1
Manganese	0·4 to 1

Other elements sometimes present in small quantities are chromium, molybdenum, copper, nickel, aluminium, titanium, vanadium, etc. Carbon is the most important element which affects its properties and it is found in cast iron in two forms, namely, free or graphitic carbon (mechanically combined with iron) and combined carbon or cementite (combined chemically with iron). Usually an increase in the percentage of combined carbon increases the hardness of cast iron.

Grey cast iron derives its name from the grey colour of its fracture which is due to the presence of the maximum graphitic free carbon and the minimum combined carbon. This is relatively soft and less brittle when compared to white cast iron.

White cast iron similarly derives its name from the colour of its bright fracture and it contains most of the carbon in the combined form and very little in the free or graphitic form. White cast iron is very brittle and is not machinable.

Welding is done only on grey iron castings for repair purposes. Welding on white cast iron is never resorted to.

The following are the important points to be borne in mind during welding of cast iron in order to ensure a satisfactory weld:

a) Cast iron is very susceptible to cracking when subjected to the stresses created by local heating during welding.

b) If proper precautions are not taken the heat-affected zone changes to white iron which is very hard and brittle.

c) Any mild steel electrode, that is used in welding of cast iron, picks up carbon and therefore behaves like steel containing higher carbon.

d) Iron castings are usually designed for rigidity, they are seldom of uniform thickness and generally they are of intricate shape with rapid changes of section. Therefore, they will not readily adjust themselves to local contraction and due to their lack of ductility, fractures are liable to occur.

The method of welding to be adopted on any particular casting depends on the nature and extent of the repair, the size and shape of the casting and the fact whether it has to be machined after welding. It is not possible to choose the particular method by any hard and fast rule. This is largely a matter of experience.

The following types of electrodes are normally used for welding cast iron:

a) Mild steel electro le with a special coating for welding cast iron,

b) Low-hydrogen electrode,

c) Nickel-cored electrode,

d) Monel-cored electrode,

e) 45/55 iron-nickel-cored electrode, and

f) Bronze electrode.

The last four types give a weld deposit which it is possible to machine after welding.

In welding cast iron, the casting should either be pre-heated to a temperature above 300°C and slowly cooled after welding or it should be kept as cold as possible by using:

a) small-size electrode,

b) low current, and

c) short beads not over 75 mm in length.

Pre-heating is a safety precuation in welding cast iron and is not essential except for complicated shapes of castings or where the presence of a hard zone is not permissible. Slow cooling after welding will prevent formation of hard zone or white cast iron at the weld junction and has also the further advantage of reducing contraction stresses, and thereby reducing the risk of cracking. For slow cooling, the welded casting should, immediately after welding, be placed in lime, asbestos or dry sand or such other insulating material. This would allow the whole of the casting to contract uniformly.

7.8 Welding of Non-ferrous Metals and Their Alloys

The application of arc welding to non-ferrous metals is a comparatively recent development. For many years, attempts have been made to carry out arc welding of copper, bronze, nickel, etc, but the results have not been satisfactory as in the case of steels. This is largely because of the greater reactivity of non-ferrous metals to oxygen and hydrogen and their usual lower melting points and higher thermal conductivities than steel. However, in recent years, considerable progress has been made in the arc welding of these materials. Some non-ferrous metals are easy to weld by the metal-arc process; others are difficult. It is usually essential to use a DC supply or an AC supply with a superimposed high frequency current for welding non-ferrous metals especially if a good quality weld is desired.

7.8.1 *Copper* — The parent metal and the filler rod should be of deoxidized arsenical copper. Pre-heat and interpass temperature of 425° to 550°C should be used and maintained, especially on heavy sections, due to the high thermal conductivity of copper. The electrode used is of deoxidized copper, coated with a flux. Bronze electrodes or copper-silicon alloy electrodes, coated with flux, may also be used where it is not necessary that the weld metal and the parent metal should be of the same composition. When welding copper, the following special points should be taken note of:

a) Allow greater root openings.

b) Use larger groove angles.

c) Use tack weld more frequently.

d) Use higher current for size of electrode and plate thickness.

e) Use higher pre-heat and interpass temperature.

f) Peen the weld to reduce stresses in the joints.

7.8.2 *Bronzes* — Bronzes commonly met with are copper-silicon alloys (silicon bronzes) and copper-tin alloys (phosphor bronze).

Silicon bronzes should not be pre-heated before welding and the interpass temperature should not be allowed to exceed 65°C. Rapid welding is required. The electrodes may be of silicon bronze or aluminium bronze which are coated with flux. The current should be maintained midway between the maximum and the minimum recommended by the manufacturer. Welding should be preferably in the flat position and the arc should be short. Silicon bronze electrodes may be used in the vertical and overhead positions. Moderate peening with flat tools will increase the mechanical properties of the weld metal and reduce stresses in the joint. No post-heat-treatment should be resorted to.

Phosphor bronze should be welded with phosphor bronze electrodes coated with flux. Phosphor bronzes should be pre-heated to a temperature between 150° to 200°C, especially if the sections are heavy, and an interpass temperature of the same magnitude should be maintained. A backing strip of matching plate is desirable. In the low tin compositions and heavy plate sections wide grooves are recommended. The current should be maintained midway between the maximum and the minimum recommended by the manufacturer. Welding should be done in the flat position as far as possible. Vertical and overhead welding may be resorted to, if absolutely necessary. In butt welding, the first two layers may be deposited using a slight weaving technique; the width of weave should not exceed two electrode diameters. The balance of the layers should be made with fast, thin string beads in order to obtain a dense, fine-grain deposit with maximum mechanical properties as welded. The arc should be short. Post-heating is not generally required. If maximum ductility in the deposit is required, a post-heat-treatment of 480°C with fast cooling is recommended.

7.8.3 *Aluminium and Aluminium Alloys* — Aluminium and many of its alloys may be readily welded by metal-arc process. Pure aluminium is used where corrosion resistance is the prime factor. Aluminium alloys are used where strength is necessary. Pure aluminium should be welded with pure aluminium electrodes, coated with flux. Aluminium-silicon alloys are welded with flux-coated aluminium-silicon alloy electrodes, and alloys are welded with flux-coated aluminium-magnesium electrodes.

Before welds are made in aluminium and its alloys, it is essential that the faces to be welded should be free from oil, grease, oxide film, etc. In order to do this, the surfaces may be brushed with wire brushes or cleaned by chemical means. A suitable cleaning solution may be made by using 3 to 5 percent caustic soda and 1 to 3 percent sodium silicate in water. For butt welding of plates up to 6 mm thickness, square butt joints with a root gap of 1 to 1·5 mm may be used. For thicknesses above 6 mm, single vee butt joint with a 90° included angle and a root gap of 1 to 1·5 mm should be used. The welding should be done in the flat position. The current used should be DC with an open-circuit voltage of 60 volts. Pre-heat and interpass temperature of about 350°C should be used and maintained, especially on heavy sections, due to high thermal conductivity of aluminium and its alloys. Where welds have to withstand corrosion, they should be heated locally to a temperature of 300° to 350°C and subjected to light hammer blows. The welds are also peened when cold to enhance their mechanical properties. The completed welds should be carefully cleaned to remove all flux residues as these are corrosive in their action if allowed to remain on the metal surfaces. This is done by scrubbing the weld seams with hot water. Where flux is likely to be trapped and where the joint is not accessible for scrubbing, further cleaning, wherever possible, should be done by immersing the welded assembly for about 10 minutes in a 5 percent solution of nitric acid heated to about 60° to 80°C. After this treatment, the seams should be washed in hot running water until the washing water is free from traces of chlorides from the flux.

7.8.4 *Nickel and Monel* — Because of the very good chemical corrosion resistance of nickel and its alloys, they are being increasingly used for the construction of chemical plants. Alloys of nickel include monel, inconel and hastelloys, but normally monel is the alloy most commonly met with Nickel is extremely sensitive to contamination by sulphur and the presence of even less than 0·05 percent of this element is enough to render it brittle and unworkable either hot or cold. Ductile nickel contains less than 0·01 percent sulphur. The electrodes used consist of pure nickel, coated with flux. The joint design, layout and welding technique are similar to those used for the metal-arc welding of steel. No pre-heating of the parent metal is necessary. Since nickel and high-nickel alloy weld metal is more viscous than steel weld metal, more careful manipulation is necessary to obtain a satisfactory weld contour. The width of a weave should never exceed three times the core wire diameter. After welding, the flux should be removed thoroughly from the welded seams. The assembly should be stress-relieved by heat-treatment at 650°C but wherever practicable it is recommended that a full anneal at 850° to 900°C should be given.

Monel is basically a 70/30 nickel/copper alloy. The flux-coated electrodes of the same composition are used for welding monel. The welding procedures are similar to those used for the metal-arc welding of mild steel. No pre-heating of the parent metal is necessary. Cleaning of the weld seams after welding should be thorough. The assembly should be stress-relieved in the same way as pure nickel.

SECTION 8

DEFECTS IN WELDS

8.1 General

The appearance of a sound weld is characterized by a uniformly rippled surface, even contour and bead width and absence of external defects, such as undercut, blowholes, surface cracks, etc

Defects in welds may be considered under the following two broad heads:

a) External defects, and
b) Internal defects.

8.2 External Defects

External defects include:

a) incorrect profile,
b) cracks,
c) crater,
d) spatter,
e) edge of plate melted off,
f) surface porosity, and
g) incompletely filled groove.

8.2.1 *Incorrect Profile* — In the case of butt welds, the defects in profile are overlap, underbead and excessive convexity and undercut. In the case of fillet welds, the defects in profile are overlap, excessive convexity, excessive concavity and undercut.

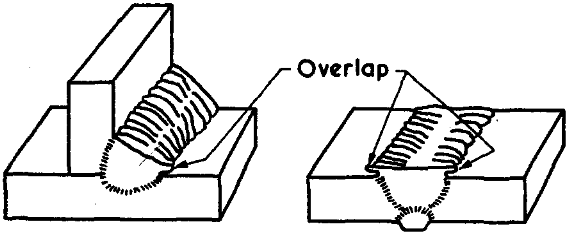
Overlap (*see* Fig. 79) is due to incorrect welding technique or incorrect electrical conditions. One of the chief causes is slow rate of welding.

Undercut (*see* Fig. 80) is due to excessive arc length, current, speed of travel and side manipulation. It is also due to the use of damp electrodes and sometimes due to the presence of heavy mill scale on the surface or magnetic arc blow.

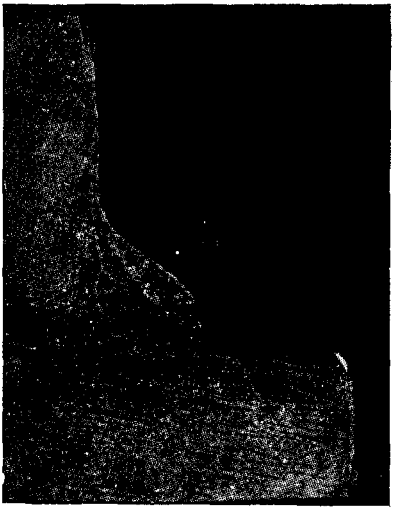
Excessive penetration bead (*see* Fig. 81) is due to one or more of the following causes:

a) Incorrect joint preparation,
b) Excessive current, and
c) Excessive arc length.

Excessive convexity is due to either the use of insufficient current or improper welding technique.



79A Schematic Diagram of Overlap in Fillet and Butt Welds



79B Overlap in Fillet Weld

FIG. 79 OVERLAP

Excessive concavity is due to excessive welding currents or excessive arc lengths.

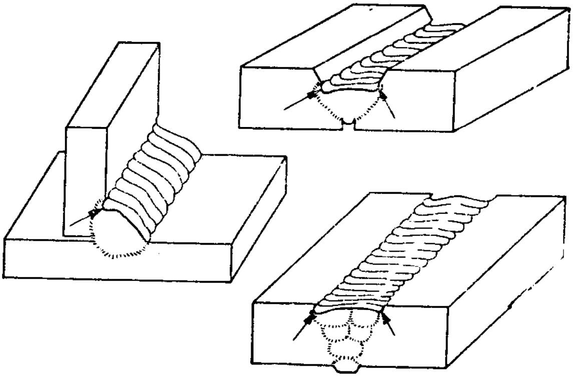
8.2.2 *Cracks* (*see* Fig. 82) — These are due to any one or a combination of one or more of the following causes:

a) Presence of localized stress,

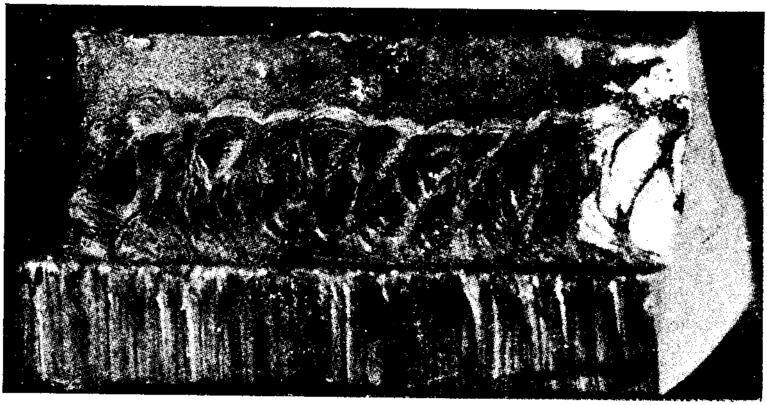
b) Difficult to weld parent metal, and

c) Improper welding technique.

Cracks may occur either in the weld metal or in the heat-affected zone of the parent material.

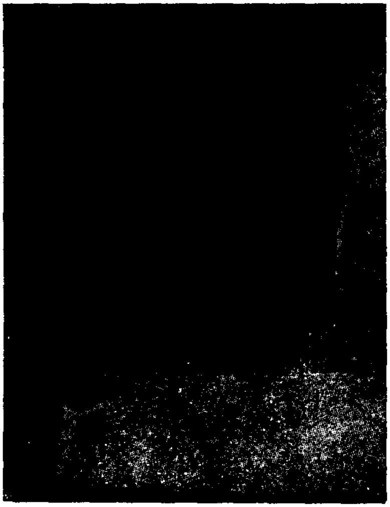


80A Schematic Diagram of Undercut in Fillet and Butt Welds

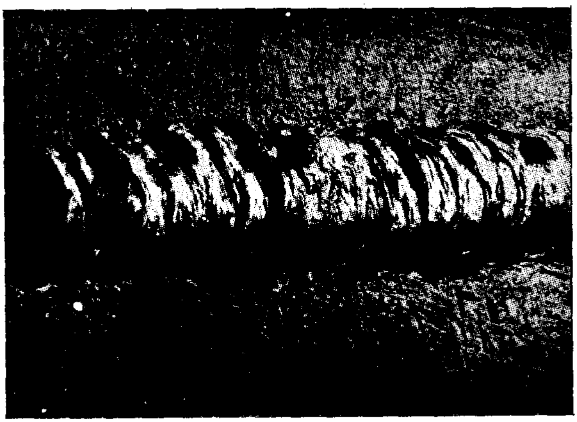


80B Undercut in Fillet Weld

Fig. 80 Undercut (*Continued*)

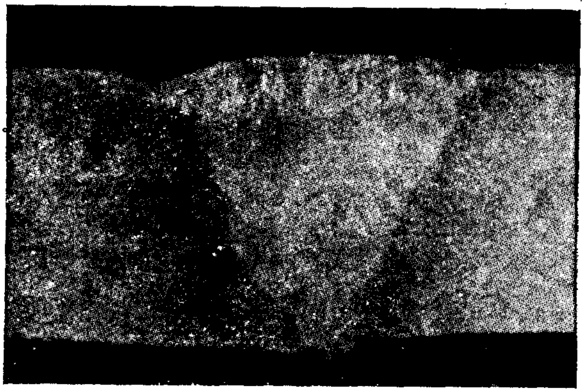


80C Undercut in Fillet Weld
(Sectional View)



80D Undercut in Butt Weld

FIG. 80 UNDERCUT (*Continued*)



80E Undercut in Butt Weld
(Sectional View)

FIG. 80 UNDERCUT

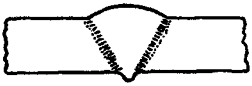
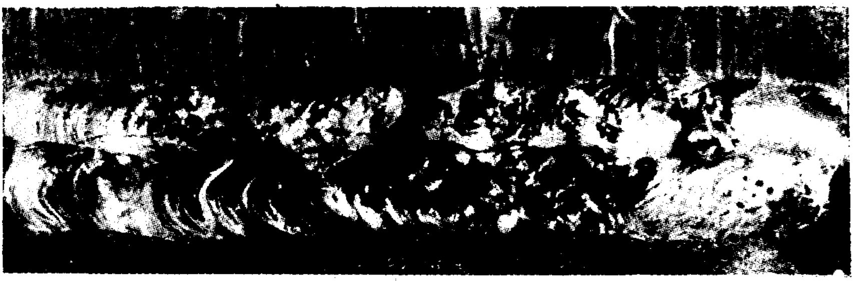


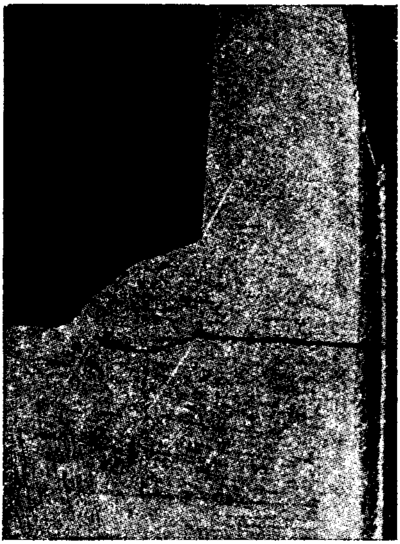
FIG. 81 EXCESSIVE PENETRATION BEAD

82A Cracks

FIG. 82 CRACKS (*Continued*)



82B Crack in Fillet Weld
(Superficial)



82C Crack in Fillet Weld
(Underbead)

FIG. 82 CRACKS (*Continued*)

82D Internal Cracks

FIG. 82 CRACKS

8.2.3 *Crater* — This is due to improper welding technique and is formed at the end of a weld run. This may be remedied by proper manipulation of the electrode. When finishing a weld, the operator should not draw away the arc quickly but should maintain the arc with no travel movement until the crater is filled up. On restriking the arc to continue the weld bead, the arc should be struck approximately 15 mm in front of the previous bead and travel backwards and then forwards in the direction of welding.

8.2.4 *Spatter* (*see* Fig. 83) — This is due to the use of either excessive current or long arc or damp electrodes.

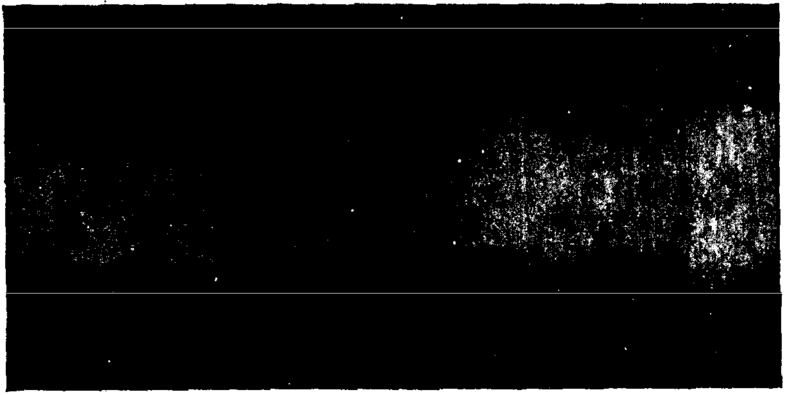


FIG. 83 SPATTER

8.2.5 *Edge of Plate Melted Off* (*see* Fig. 84) — This occurs in lap joints only and is due to the use of oversize electrode, excessive current or wrong manipulation of the electrode.

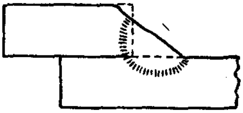


FIG. 84 EDGE OF PLATE MELTED OFF

8.2.6 *Surface Porosity* (*see* Fig. 85) — This occurs due to the use of a wrong type of electrode, incorrect electrical conditions, excessive arc length and/or improper welding technique.

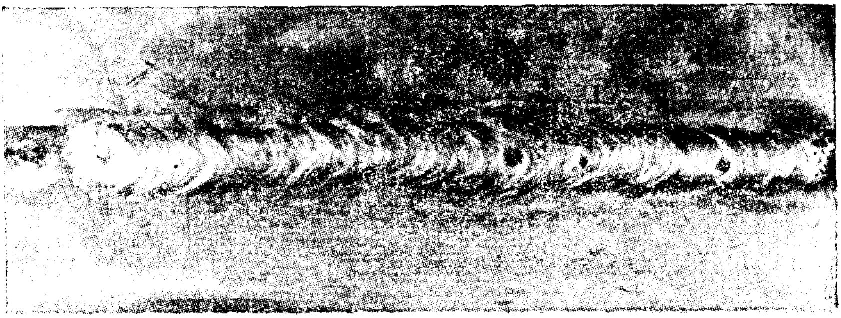


FIG. 85 SURFACE POROSITY

8.2.7 *Incompletely Filled Groove* (*see* Fig. 86) — This defect occurs in butt welds and is due to inadequate deposition of weld metal and the use of incorrect size of electrode.

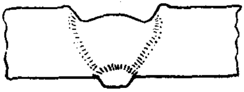


FIG. 86 INCOMPLETELY FILLED GROOVE

8.3 Internal Defects

Internal defects include:

a) blowholes and internal porosity,

b) cracks,

c) inclusions,

d) lack of fusion, and

e) incomplete penetration.

8.3.1 *Blowholes and Internal Porosity* (*see* Fig. 87) — These are due to one or more of the following causes:

a) Wrong type of electrode,

b) Excessive current,

c) Excessive arc length,

d) Unsatisfactory parent metal, and

e) Improper welding technique.

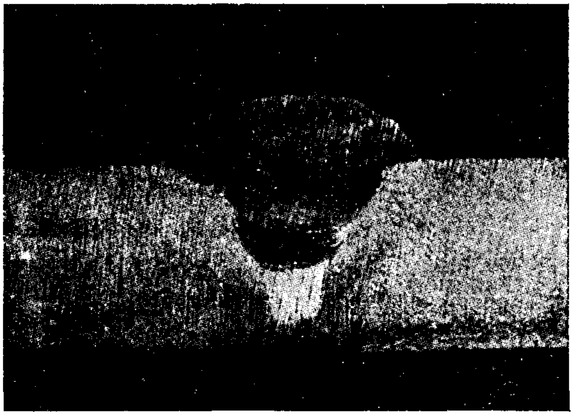


Fig. 87 Blowholes and Internal Porosity

8.3.2 *Cracks* — The causes for internal cracks are the same as those for external cracks (*see* Fig. 82).

8.3.3 *Inclusions* (*see* Fig. 88) — These occur due to one or more of the following causes:

a) Incorrect joint,

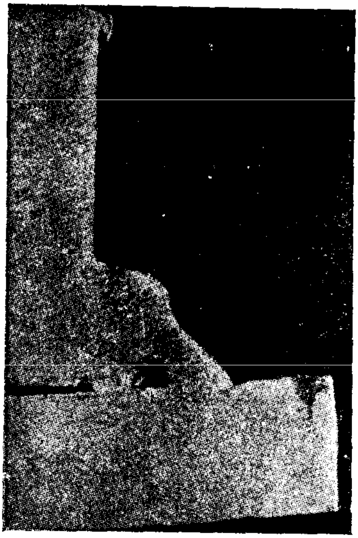
b) Wrong size and type of electrode,

c) Excessive current,

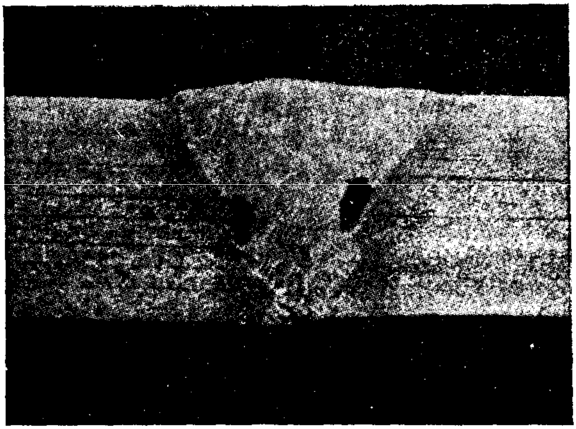
d) Excessive arc length,

e) Improper welding technique, and

f) Inadequate cleaning of each run in multi-run welding.



88A Slag Inclusion in Fillet Weld



88B Slag Inclusion in Butt Weld

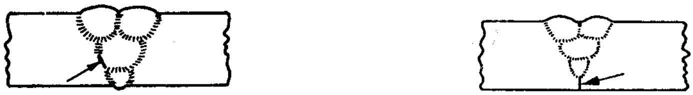
FIG. 88 INCLUSIONS

8.3.4 *Lack of Fusion* (*see* Fig. 89) — This may be caused due to the following reasons:

a) Failure to raise the temperature of the parent metal or of the previously deposited weld metal to the melting point; and

b) Failure to dissolve during welding, the oxides or other foreign material present on the surfaces with which the deposited metal should fuse.

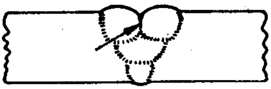
Lack of fusion is best avoided by keeping the surfaces to be welded free from injurious foreign material and by using proper welding techniques.



89A Lack of Side Fusion

89B Lack of Root Fusion

89C Lack of Root Fusion



89D Lack of Inter-Run Fusion

Fig. 89 Lack of Fusion

8.3.5 *Incomplete Penetration* (*see* Fig. 90) — This is due to:

a) failure of the root face of a butt weld to reach fusion temperature for its entire depth, or

b) failure of the weld metal to reach the root of a fillet weld leaving a void.

It may also be due to the use of:

c) oversize electrode,

d) excessive speed of travel, or

e) less current.

8.4 Elimination of Defects

It is pointed out that most of the defects in welding may be eliminated by:

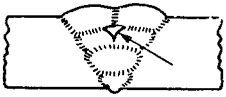
a) using correct joint preparation,

b) use of correct type of electrode,

c) use of correct electrical conditions,

d) maintaining correct arc length, and

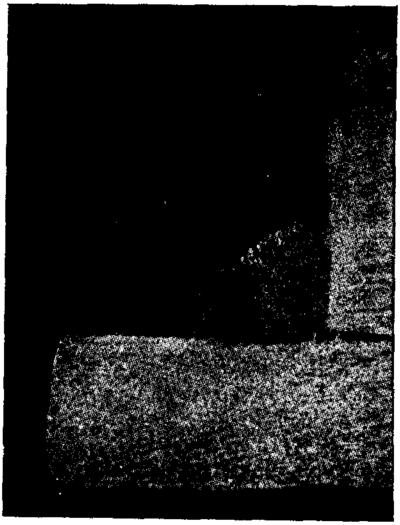
e) using correct welding technique.



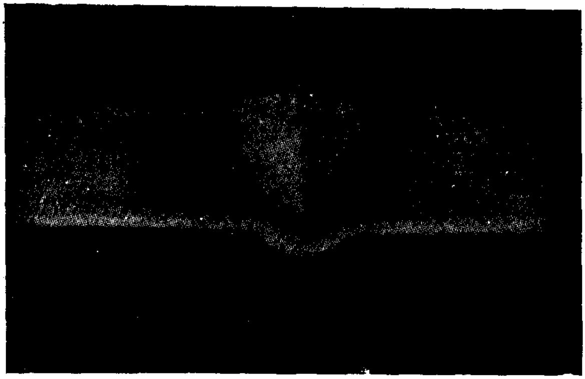
90A Incomplete Inter-Run Penetration

90B Incomplete Root Penetration

FIG. 90 INCOMPLETE PENETRATION (*Continued*)

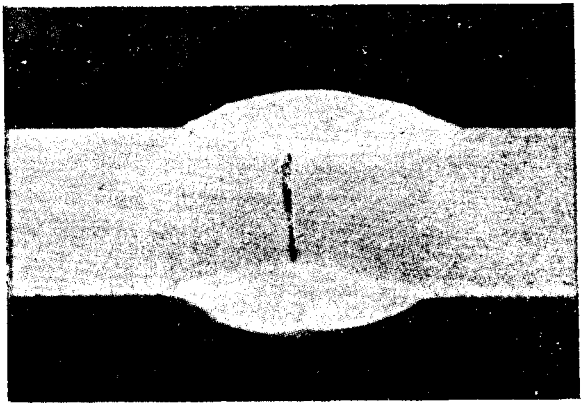


90C Lack of Root Penetration in Fillet Weld



90D Lack of Root Penetration in Butt Weld

FIG. 90 INCOMPLETE PENETRATION (*Continued*)



90E Incomplete Penetration in Butt Weld

FIG. 90 INCOMPLETE PENETRATION

SECTION 9

INSPECTION AND TESTING OF WELDS

9.1 General

With the rapid advance made in the science and technique of welding in the last few decades, inspection and testing of welds have assumed great importance. To obtain a dependable joint, it is necessary to inspect and exercise adequate control before, during and after welding. It is also necessary to draw samples on a scientific basis and test them not only to control the quality of the weld, but also to assess the skill and ability of the welder.

Inspection and testing procedures for different welding processes vary considerably. The various tests to be conducted on welded joints are determined mainly by the service conditions to which the welded components will be subjected to.

9.2 Inspection

Inspection is made in three stages, namely

a) before welding,
b) during welding, and
c) after welding.

9.2.1 *Inspection before welding* consists in ascertaining whether:

a) proper facilities exist for storing and drying of electrodes;
b) the operators selected to do the job are familiar with the type of work, the electrodes and the welding machines they are required to handle;
c) proper type of equipment and suitable sizes and types of electrodes have been chosen for the work;
d) the material to be welded is of weldable quality;
e) the edges have been properly prepared for welding, are easily accessible and are devoid of surface defects. This calls for examination of contour and dimensions of the joints with the help of suitable gauges;
f) polarity of the electrode in the case of DC welding currents; and
g) whether any jigs or fixtures are necessary to ensure proper alignment so as to prevent undue distortion later on.

9.2.2 *Inspection during welding* consists of:

a) studying the sequence of weld deposits, and

b) examining whether each weld is cleaned adequately before making the next run in multi-run welding.

It is possible to judge from the shape of the deposit, electrode spatter and under- or over-flushing of the metal during welding whether the amperage, speed of travel, arc length and manipulation of the electrode are correct.

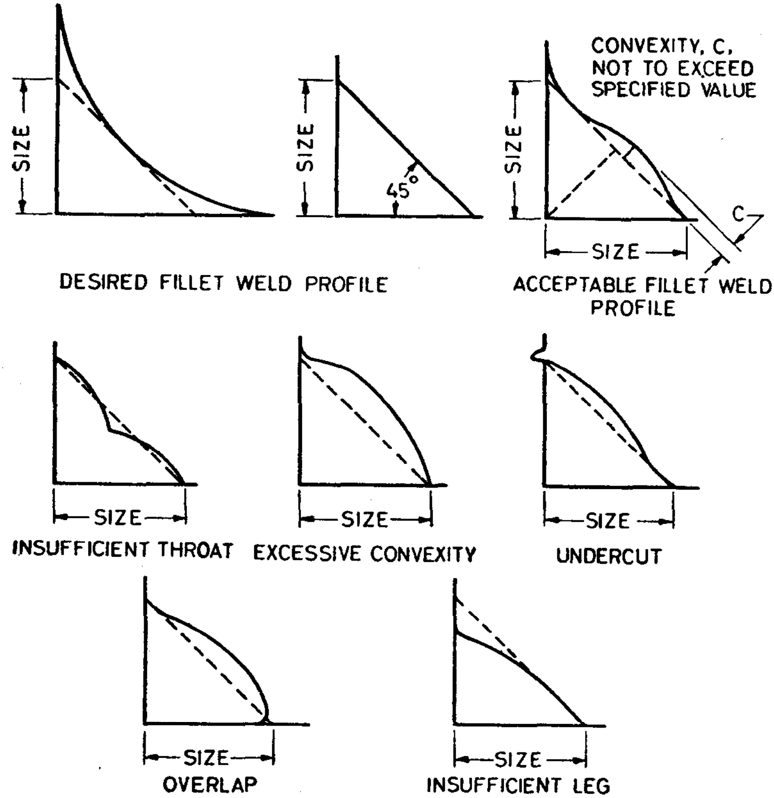
9.2.3 *Inspection after welding* consists in visual examination of the welds after their execution. Surface defects in and around the welds, such as cracks (longitudinal and transverse) (*see* Fig. 82), undercut (*see* Fig. 80), underflush, overlap (*see* Fig. 79), excessive convexity formation of small craters and gauge marks may be detected by visual examination and rectified suitably before subjecting the welds to further inspection and testing. The defects may be detected by examining the surfaces of the welds with the naked eye or with the help of a low-power magnifying glass, and with a hammer and stethoscope. The acceptable and defective butt and fillet weld profiles are shown in Fig. 91. Minute surface cracks may also be detected with the help of the ordinary *paraffin and chalk method* or *a magnetic crack detector* or by the *fluorescent flaw detection method.*

The paraffin and chalk method consists in smearing the surface under examination with paraffin when the surface cracks, if any, get filled with it. The excessive paraffin is then wiped out and the surface coated with white wash. When the white wash dries up, the location of any crack shows up by the paraffin seeping from the crack and discolouration of the white wash.

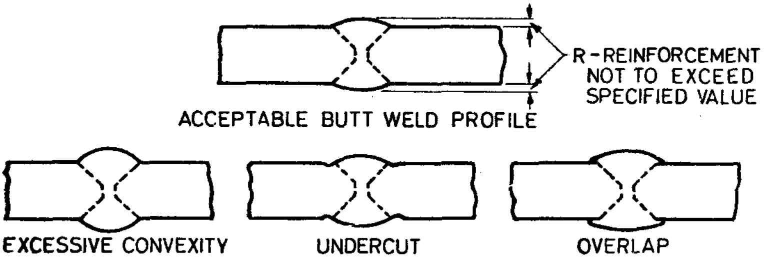
The magnetic method of flaw detection is applicable only to magnetic materials and consists in applying a magnetic field and sprinkling fine iron powder held in suspension in a suitable medium. When there is a surface crack in the job under test, due to the externally imposed magnetic field, the edges of the crack assume opposite polarity. The soft iron particles sprinkled on the surface under examination assume the respective polarity and array themselves along the edges of the crack. Thus, under good illumination the cracks are prominently visible.

The fluorescent flaw detection method is applicable both to ferrous and non-ferrous materials, and is based on the principle that if a suitable fluorescent chemical held in suspension in a suitable medium is applied over the surface under inspection, the fluorescent liquid enters into the cracks. The excess liquid on the surfaces is wiped off. The quantity of the fluorescent chemical, therefore, is more inside the cracks. When an ultra violet source of light is made to illuminate the surface under inspection, the cracks filled with fluorescent chemical glow, thus making themselves prominently visible.

Due to the very nature of the welding operation, defects which are confined to the interior of the welds also occur. These internal defects are porosity, blowholes (*see* Fig. 87), slag inclusions (*see* Fig. 88), underbead cracks (*see* Fig. 82), root defects or incomplete penetration (*see* Fig. 90) and internal cracks (transverse and longitudinal) (*see* Fig. 82).



91A Defective Fillet Weld Profiles


R-REINFORCEMENT NOT TO EXCEED SPECIFIED VALUE
ACCEPTABLE BUTT WELD PROFILE
EXCESSIVE CONVEXITY
UNDERCUT
OVERLAP

91B Defective Butt Weld Profiles

Fig. 91 Acceptable and Defective Butt and Fillet Weld Profiles

These defects may be detected by destructive or non-destructive tests. Destructive tests consist in cutting the welds and examining the section for the presence of defects. For detecting incomplete penetration, a suitably sectioned weld may be deep-etched and inspected for the extent of penetration.

Specimens to be tested shall be etched for either of the following two purposes:

a) to determine the soundness of a weld, or

b) to determine the location of a weld.

For tests in which the dimensions of the specimen, the procedure or the results depend upon the location of the weld, the surface of the specimen at and adjacent to the weld shall first be etched with any reagent which makes the boundary between the weld metal and the base metal visible, if the boundary is not already distinctly visible.

Some reagents commonly used and the method of their application for testing welds in carbon steels and low alloy steels (with 5 percent or less of alloying elements) are described below:

a) *Hydrochloric acid* — equal parts by volume of concentrated hydrochloric (muriatic) acid and water. The weld is immersed in this reagent at or near the boiling temperature. Hydrochloric acid will etch satisfactorily unpolished surfaces. It will usually enlarge gas pockets and dissolve slag inclusions, enlarging the resulting cavities.

b) *Ammonium persulphate* — one part of ammonium persulphate (solid) to nine parts of water by weight. The surface of the weld is vigorously rubbed with cotton saturated with this reagent at room temperature. Defects, if any, will be exposed.

c) *Iodine and potassium iodide* — one part of powdered iodine (solid) to twelve parts of a solution of potassium iodide by weight. The solution should consist of one part of potassium iodide to five parts of water by weight. The surface of the weld is brushed with this reagent at room temperature. Defects, if any, will be revealed.

d) *Nitric acid* — one part of concentrated nitric acid to three parts of water by volume. Always the acid should be poured into the water when diluting. *Nitric acid causes bad stains and severe burns.* Either this reagent is applied to the surface of the weld with a glass stirring rod at room temperature, or the weld is immersed in boiling reagent provided the room is well ventilated. Nitric acid etches rapidly. It should be used on polished surfaces only, and will show the refined zone as well as the weld metal zone.

After etching, the weld shall immediately be washed in clean water, preferably hot water; the excess water shall be removed; the etched surface shall then be immersed in ethyl alcohol, removed and dried, preferably in a warm air blast. The appearance shall be preserved by coating with a thin clear lacquer.

The deep-etch method is feasible only on test samples prepared by welding but not on the actual jobs. In such cases, semi-destructive method or non-destructive methods, such as X-ray or gamma-ray radiography or ultrasonic testing, may have to be resorted to.

Semi-destructive test may be carried out on butt joints. The method consists of using a special circular conical saw which will cut out the full thickness of the joint in the form of a boat. One glance at this cut out specimen will show whether fusion has been proper and whether the deposit is free from porosity or slag inclusion. Furthermore, the specimen may be machined into a miniature tensile, impact or bend test piece. Handy machines working on this principle are available commercially and have been used successfully in the construction of welded pipe lines, tanks, etc. Another method consists of drilling out plugs which is called 'trepanning'. In this case, however, filling up the plugs by welding becomes a difficult matter.

The method of testing welds by X-ray radiography depends on:

a) the fact that X-rays of suitable wavelengths penetrate through metals,

b) the capacity of the material under test to absorb X-rays which is related to the density of the materials, and

c) the capacity of X-rays to affect sensitized photographic plates.

The intensity of the X-ray beam which has passed through an internal defect in the material, such as a blowhole, slag inclusion, crack or void, will be greater than that which has passed through the material containing no such defects. The locations on the photographic plate or film just beneath a defect, therefore, will receive more of X-ray energy and thus will appear as dark spots or streaks, as the case may be, in the radiograph.

The method of inspection using gamma rays is based on the same principle as the X-ray radiographic inspection method. But, the source of radiation in the case of gamma-ray radiography is a radio-isotope, such as Cobalt 60 or Irridium 192. These isotopes emit gamma rays, wave-lengths of which are very much shorter than X-rays. Hence, they have more penetration power. These are, therefore, suitable for examination of thicker sections. As the source in the case of gamma-ray radiography emits gamma rays in all directions, this method is very well suited for industrial non-destructive testing of more than one sample simultaneously.

Both the above methods employ radiations which, beyond certain dosages are detrimental to human beings. It is, therefore, necessary to take suitable precautions while employing these methods.

The ultrasonic method of non-destructive testing for detection of internal defects depends on the fact that sound wave of frequencies higher than the maximum audible range propagates through a medium of uniform elasticity but gets reflected whenever there is a sudden change in the elastic properties of the medium. Thus, when an ultrasonic beam is made to pass through a material containing a void or an inclusion, the beam, in addition to getting reflected from the boundaries of the material under test, also gets reflected from the walls of the internal discontinuities. By suitably amplifying and feeding the ultrasonic energy received from the boundaries and the internal defects to cathode-ray oscillograph, it is possible to detect the presence of internal discontinuities and also to locate their approximate positions. The principles involved and the operation of the instrument are very simple, but require a lot of experience on the part of the operator to interpret the results obtained and to correlate them with the defects, their nature, size and distribution. As far as testing of welds is concerned, this method is not yet well established in this country.

9.3 Testing of welds

In order to ensure the quality of welds, it is necessary to have an efficient system of inspection and testing. In general, mechanical tests are the least expensive and most reliable for assessing the weld quality. Therefore, mechanical tests are most widely carried out.

Though there is complete unanimity of opinion among the welding engineers on the properties to be determined and the procedure of test, there is a wide divergence in the shape and size of test specimens and the details of test procedures. The results obtained on test specimens prescribed in different codes and specifications, should not therefore, be compared directly.

Only routine tests undertaken in the testing of welds are described in the following paragraphs. Tests are conducted on welded samples to assess the quality of the electrodes or the ability of the welder or the weldability of the base metal or to determine the strength of the welded joints. The mechanical tests conducted on welds, therefore, will depend on the purpose in view. They will also vary from one method of welding to another depending on the special characteristics of each method. The usual tests are:

a) tensile test,
b) bend test, and
c) impact test.

Transverse and longitudinal shear strength tests are conducted for testing fillet welded joints.

Tests, such as fillet weld penetration test, tee-joint fillet weld hot cracking test and cruciform fillet weld tensile test are conducted to assess the quality of electrodes meant for fillet welding.

9.3.1 *Tests on Weld Metal* — Tensile and impact tests are conducted on standard specimens prepared from the weld metal. Ultimate tensile strength, percentage reduction in areas and percentage elongation are determined on standard tensile specimens and impact strength on standard Izod or Charpy specimens. For the purpose of preparing these specimens, the weld metal is deposited between the chamfered edges of two plates of suitable thickness and under standard conditions of included angle, edge preparation and root gap (*see* Appendix B of IS : 814-1963). The method of preparing the all-weld metal test specimens is shown diagrammatically in Fig. 92. Standard tensile and Izod test specimens are machined from all-weld metal and are tested in accordance with standard testing procedures. These tests give an idea of the mechanical properties of the deposited weld metal.

9.3.2 *Tests on Butt-Welded Joints* — Tensile and bend tests are conducted on standard specimens machined from test samples welded in continuation of the actual weld on the job with a view to ascertaining the strength of the joint.

Three types of bend tests are conducted on butt-welded test specimens. These are:

a) root bend test,
b) face bend test, and
c) guided bend test.

In the root bend test, the root of the butt weld is kept on the tension side while bending the specimen around a mandrel of specified diameter and through an angle of 180°. This test will easily show up any root defects or inadequate penetration.

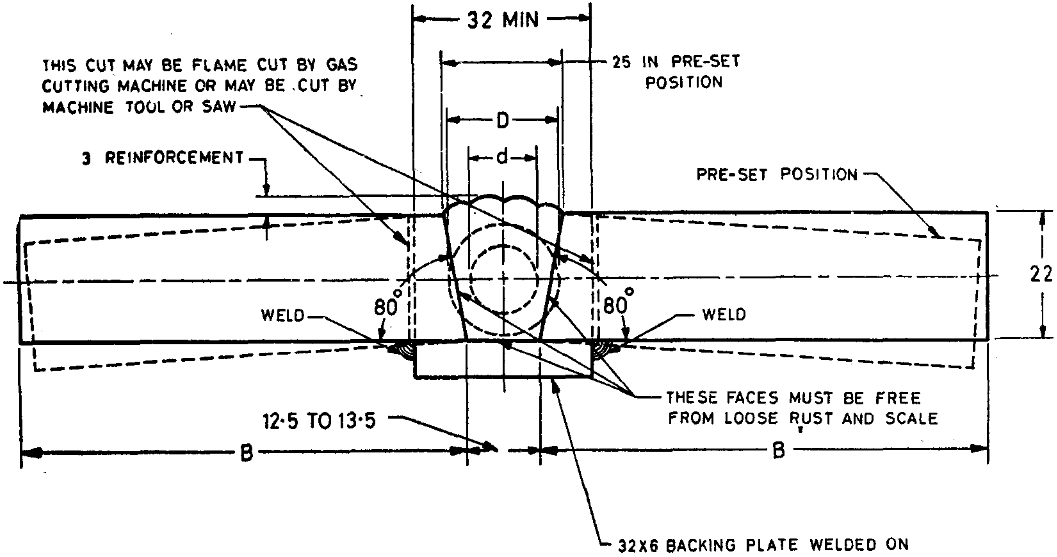
In the face bend test, the face of the butt weld is kept under tension during the test and bent through an angle of 180° around a mandrel of specified diameter. This test will easily show up any inadequate penetration into the sides of the groove. This is also an index of the ductility of the weld metal (*see* Fig. 93).

The guided bend test is similar to the other two except for the fact that this test is conducted under controlled bending conditions (*see* Fig. 94). The requirements of the test are the same as for 'root bend test' and 'face bend test'.

In all these bend tests, no crack or defect should appear at the outer surface of the test specimen greater than 3 mm measured across the specimen or 1·5 mm measured along the length of the specimen.

Sometimes, Izod impact tests are also conducted on standard specimens prepared in a direction transverse to the weld seam from butt-welded test specimens in such a way that one of the notches is cut in the centre of the face of the weld and the two adjacent ones are at a standard distance of 22 mm on either side and at an angle of 180° to the middle notch.

This test is conducted to assess the capacity of the weld to withstand shock load and the effect of heat on the parent plates adjacent to the weld seam.


32 MIN
25 IN PRE-SET POSITION
THIS CUT MAY BE FLAME CUT BY GAS CUTTING MACHINE OR MAY BE CUT BY MACHINE TOOL OR SAW
D
d
3 REINFORCEMENT
PRE-SET POSITION
22
80°
80°
WELD
WELD
THESE FACES MUST BE FREE FROM LOOSE RUST AND SCALE
12·5 TO 13·5
B
B
32X6 BACKING PLATE WELDED ON

Length of welded joints $=180$

Diameter $D=15$ *Min* to 25 *Max* to suit tensile testing machine grips

and

d shall correspond to the relevant gauge diameter in the case of tensile test specimens 10mm^2 in the case of impact test specimens.

All dimensions in millimetres.

Fig. 92 Method of Preparation of All-Weld Metal Test Specimen

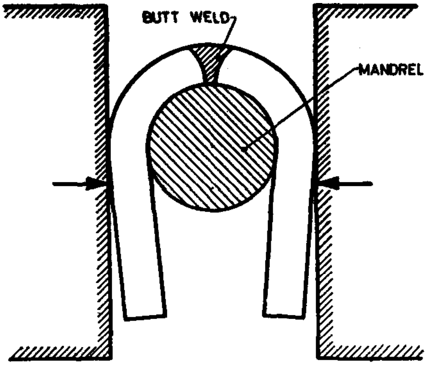


FIG. 93 BEND TEST SPECIMEN TESTED FOR FACE BEND

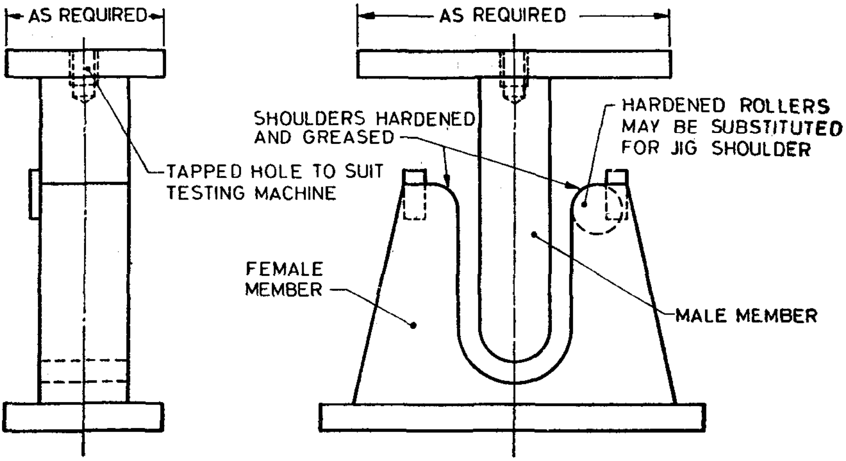
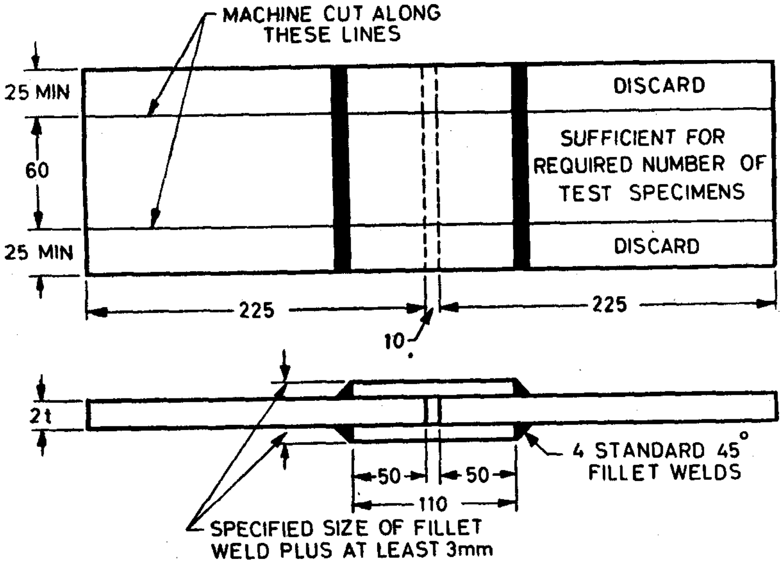

AS REQUIRED
AS REQUIRED
SHOULDERS HARDENED AND GREASED
HARDENED ROLLERS MAY BE SUBSTITUTED FOR JIG SHOULDER
TAPPED HOLE TO SUIT TESTING MACHINE
FEMALE MEMBER
MALE MEMBER

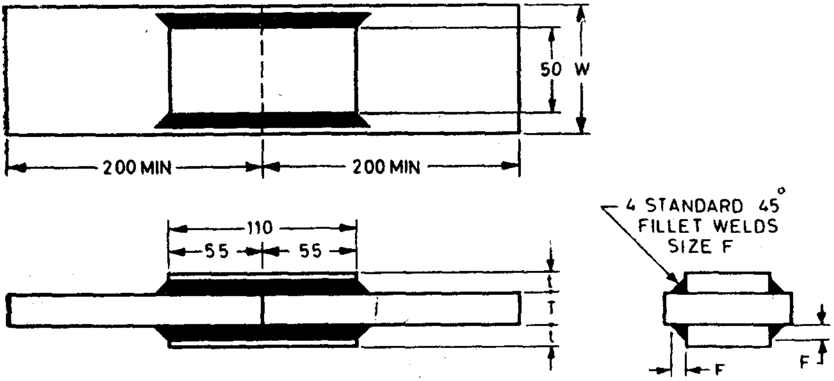
FIG. 94 JIG FOR GUIDED BEND TEST

9.3.3 *Tests on Fillet-Welded Joints* — Tensile test on standard specimens with fillet welds in the transverse and in the longitudinal direction are conducted to determine their shear strength in the transverse and longitudinal directions respectively. The method of preparing the transverse and longitudinal fillet weld specimens is shown in Fig. 95 and Fig. 96 respectively.


MACHINE CUT ALONG THESE LINES
25 MIN
60
25 MIN
DISCARD
SUFFICIENT FOR REQUIRED NUMBER OF TEST SPECIMENS
DISCARD
225
225
10
2t
4 STANDARD 45° FILLET WELDS
50
50
110
SPECIFIED SIZE OF FILLET WELD PLUS AT LEAST 3mm

All dimensions in millimetres.

Fig. 95 Method of Preparing Transverse Fillet Weld Shearing Specimen



All dimensions in millimetres.

Fig. 96 Method of Preparing Longitudinal Fillet Weld Shearing Specimen After Welding

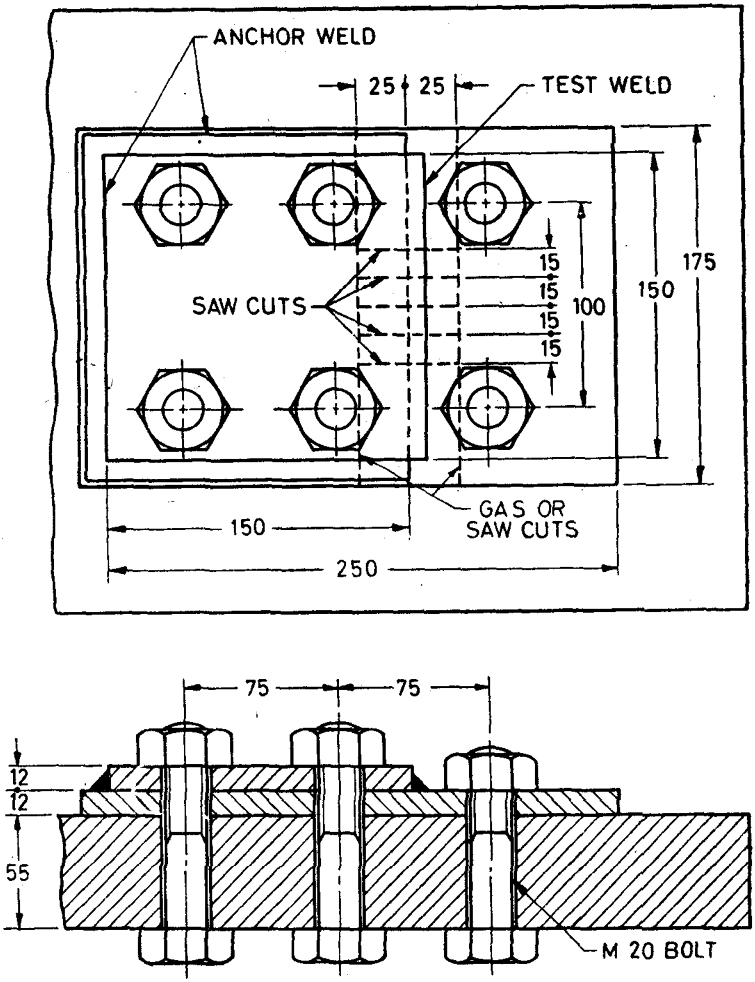
The width of the specimen is measured in millimetres. The specimen is pulled under a tensile load and the maximum load in kilograms for rupture to occur is determined. The shear strength of welds in kilograms per millimetre length of weld is obtained by dividing the maximum force by twice the width of the specimen. The shear strength of the welds in kilograms per square millimetre may be obtained by dividing the shear strength in kilograms per millimetre length by the average throat dimensions of the welds in millimetres. The above shear strength values give an idea of the quality of the fillet weld in the transverse and longitudinal directions.

The various tensile, bend, shear and impact tests described above are conducted in the laboratory with the help of standard tensile and impact testing machines.

9.3.4 *Other Tests.* — Besides the routine tests described above, there are various special tests conducted on welds to evaluate specific properties for particular applications, such as *weldability*, *corrosion resistance*, *resistance to oxidation* and *resistance to wear.*

Of these, *weldability test* for the parent metal deserves elaboration. This may be measured in terms of the capacity of the base metal and the filler metal or electrode to produce a crack-free and mechanically satisfactory welded joint. A simple test was devised by Reeve to assess the weldability by laying a weld under restraint, other conditions remaining ideal. The method of preparing Reeve's fillet weld test specimen for assessing weldability is shown in Fig. 97. Two test plates are bolted firmly to a heavy base plate. The two test plates are fixed by fillet anchor welds laid along the longitudinal edges. A test weld is deposited under standard conditions. The welds are allowed to cool under restraint and are kept for 48 hours. They are then sawn out as shown in the figure. The surface for test welds should not show any evidence of cracks. The transverse section through welds is examined visually or with the help of magnetic or fluorescent methods of detection for presence of cracks in the weld and in the heat-affected zone. The nature and the degree of cracking around the heat-affected zone determine the weldability of steel under specified conditions. Hardness survey is also made in the heat-affected zone, and if the maximum diamond hardness exceeds 370 the weld is viewed with suspicion even if it does not show any evidence of cracks.

Recently, a test called the *controlled thermal severity test* has been devised for checking the susceptibility to cracking of heat-affected zone in any steel electrode combination using a minimum of material. By conducting a series of tests with various thermal severities, it is possible to assess the general weldability of any steel/electrode combination. Total thickness of plate through which heat flows away from the weld can be expressed in terms of the thermal severity number '(TSN)' of the joint. The unit of thermal severity has been taken as the heat flows through one thickness of 1/4 in. (6·35 mm) plate, so that a joint with thermal severity of 2 (TSN 2)

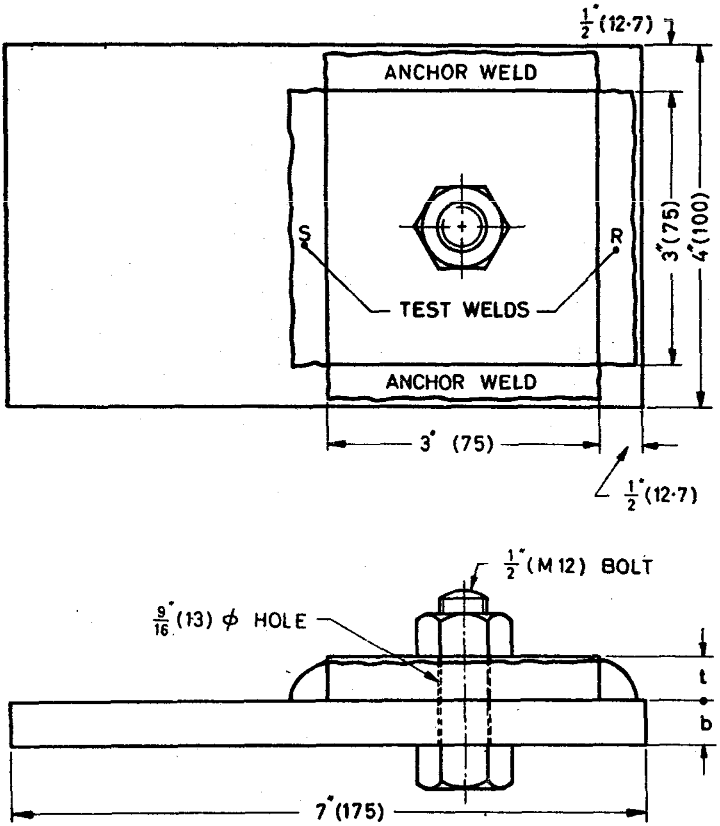


All dimensions in millimetres.

FIG. 97 METHOD OF PREPARING REEVE'S FILLET WELD TEST SPECIMEN FOR ASSESSING WELDABILITY

is obtained by depositing a weld in a position where heat flows away from it through two thicknesses of 1/4 in. (6·35 mm) plate (for example a 1/4 in. butt weld). Two thicknesses of 1/2 in. plate adjacent to a weld give a joint of (TSN 4), a fillet weld in a T-joint in 1/2 in. (12·7 mm) plate has (TSN 6) and so on. TSN is four times the thickness of the plate expressed in inches, through which heat is conducted away from the weld.

The controlled thermal severity test assembly consists of two plates of steel under test, bolted and anchor welded together on two opposite edges as shown in Fig. 98.



Dimensions in brackets are in millimetres.

FIG. 98 ASSEMBLY FOR CONTROLLED THERMAL SEVERITY TEST

The test welds are deposited on the other two edges. One of the test welds may be considered to have a thermal severity equivalent to that of a butt weld in view of the two directional flow of the heat from the weld metal and the other a thermal severity equivalent to that of a lap joint or T-joint fillet weld in view of the three directional flow of heat.

The test assembly is sectioned as shown in Fig. 99 and subjected to macro, mirco and hardness tests.

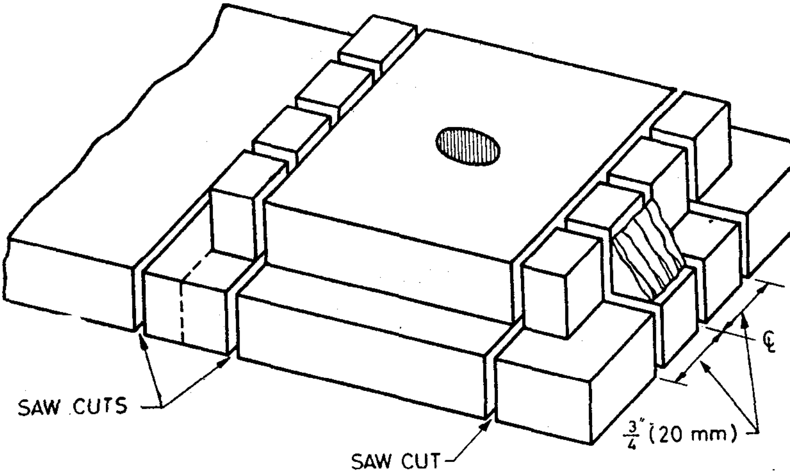


FIG. 99 SECTIONED TEST ASSEMBLY FOR MACRO, MICRO AND HARDNESS TESTS

From the readily available charts and the presence or absence of cracks in the heat-affected zone in various thermal severities, the weldability index can be fixed. Knowing the weldability index, the thermal severity number of the job and the gauge of electrode to be used, it is possible to determine the minimum pre-heat temperature required before welding.

SECTION 10

SAFETY IN WELDING

10.1 General

In any sphere of activity, it is necessary to know and understand the sources of danger to ensure safety. In welding and allied processes, there are certain easily defined sources of danger which should be constantly borne in mind.

These sources fall into three categories, namely:

a) dangers associated with gas welding and cutting,

b) dangers associated with electric welding processes, and

c) dangers common to both the welding processes.

10.2 Dangers Associated with Gas Welding and Cutting

In these processes, combustible gas like acetylene is used for obtaining high temperature flame. Acetylene is obtained commercially either from cylinders in which the gas is compressed and dissolved in acetone (DA, that is, dissolved acetylene) or in generators on the spot by the reaction of water on calcium carbide.

Cylinders filled with different gases are painted with different colours for identification. To prevent the fittings being interchanged between cylinders of combustible and non-combustible gases, the valve outlets are screwed left hand and right hand respectively and also connections have facet marks.

The person handling these gas generators and blowpipes should be completely familiar with the correct procedures for handling the equipment safely. Some of the essential precautions to be taken in the use of gas cylinders are given below:

When using oxygen and dissolved acetylene,

DO NOT

a) tamper with cylinders or fittings;

b) attempt to mix gases in a cylinder;

c) use cylinders for any purpose other than welding or cutting;

d) stack acetylene cylinders on their side and use upright;

e) expose cylinders to heat;

f) use oil or grease near oxygen;

g) use faulty apparatus, that is regulator, hose, torch, etc; and

h) test for leakage with a naked flame.

DO

a) light the blowpipe properly,
b) store the cylinders properly,
c) keep full and empty cylinders apart,
d) move only one cylinder at a time or by crane in a properly designed cradle,
e) keep cylinder valve sockets clean and snift out any loose dirt before fitting regulators or fittings,
f) shut cylinder valves when work has stopped or the cylinder is empty,
g) open the cylinder valves slowly, and
h) leave the valve key in position especially on the acetylene cylinder.

If the blowpipe back-fires, it is because:

a) the regulators are not set to the correct pressure, or
b) light has been applied before the flow of fuel gas is properly established.

To light the blowpipe, the following procedure should be followed:

a) Set the regulators to the recommended working pressure.
b) Keep the blowpipe nozzle away from any source of ignition (pilot light, smouldering tool, etc) until the fuel gas is flowing freely from the nozzle.
c) The use of spark lighter is recommended for lighting blowpipes.

If the flame snaps out when the blowpipe is in use, it is because:

a) the regulator pressure or gas flow or both are incorrect, either too high or too low;
b) the nozzle is obstructed;
c) the nozzle is held too close to the work; or
d) the nozzle has become overheated.

When the flame snaps out, the following procedure should be adopted:

Completely shut both blowpipe valves, check regulator setting and cylinder pressures, and re-light in accordance with the procedure given above. In the case of (d), cool the blowpipe in water.

If an acetylene cylinder is heated accidentally or becomes hot due to excessive or severe back fire from the use of faulty equipment, it should be dealt with promptly as follows:

a) Shut the valve.
b) Detach regulator or other fitting.
c) Take the cylinder outdoors in the open air at once.

d) Immerse in or apply water copiously to keep the cylinder cool.

e) Contact the suppliers immediately and ask for further advice.

When acetylene generators are used in place of dissolved acetylene, their installation and use should be done in accordance with the directions given in the Petroleum and Carbide of Calcium Manual, 1953, Government of India. The following extra precautions should be taken:

a) The generator should be cleaned and recharged, and the air mixture blown off in the open, well clear of any possible source of heat;

b) When charged with carbide, it should not be moved by crane or derrick;

c) When not in use, it should not be stored in any room in which open lights or fires are used unless free of carbide and thoroughly purged;

d) The generator when in use, shall not be near any source of heat; and

e) The generator should be operated by a responsible person familiar with its operation and maintenance; and

f) The generator should be fitted with a hydraulic back pressure valve which should be adequately filled with water.

10.3 Dangers Associated with Electric Welding Processes

In this process, all the welding equipment used, like welding generators, transformers, cables, electrode holders, hand screens (or shields) and electrodes, should be of standard quality manufactured according to sound engineering practice. Wherever there is an Indian Standard specification for any of these equipment, it is safe to use the equipment and accessories conforming to them. Workmen employed to operate arc welding equipment should be properly instructed and trained to operate such equipment. Voltages required for arc welding are low and normally will not cause injury or severe shock and so parts having these voltages are liable to be handled carelessly. Under certain circumstances, however, these voltages are fatal and it is absolutely essential that welders should know how to avoid electric shocks. For example, when the welder's protective clothing is damp or wet, it may lose its insulating property. This danger is particularly marked in a hot country like India where the welder perspires profusely. The welder should never permit contact of his body with any metallic element carrying voltage, without proper insulation. It should not be assumed that because contact with an electrode at one time is not harmful, similar contacts at other times will be harmless.

When the welder is not working, the electrode should be removed from the holder and the welding machine switched off, and the holder kept in such a way that it will not make electrical contact with persons or conducting objects. The use of fully insulated type of holders is strongly recommended.

Welders should check their equipment regularly to see that electrical connections and insulation on the holders and cables are in good order. If any repair is necessary, it should be done only by qualified personnel.

When using a DC generator set with an open-circuit voltage of 45 to 65 volts, danger of shock is slight, but when AC transformer sets with voltages between 80 to 100 (and hence peak values higher than 100 volts on the welding or secondary side) are used, the danger is quite pronounced. This is more so when working in wet weather.

It should also be remembered that the cables carrying current, either to the motor generator sets or to the primary winding of transformer sets, will be at voltages between 200 to 550 volts. To prevent accidents, these cables and connections to the mains and welding sets, should be sound, the cables should be of one piece without intermediate connectors and preferably of armoured and screened type.

In all cases, the cables, both from supply mains and from welding sets to the operators, should be as short as possible. They should be so placed as to be clear of passageways, stairs, roadways and the like where they are likely to get damaged.

10.4 Dangers Common to Both the Welding Processes

The first and foremost danger, associated with both the types of welding processes, is the possible incidence of fire if welding were done near combustible materials. Welding should be done at a location specially designed for this purpose. If this is not possible, full precaution should be taken to see that guards are used to confine the heat sparks and slag and to prevent fire hazards.

The operator should take full precautions to protect himself against arc rays, flying slag and drops of molten metal. Helmets (or head screens), along with protective clothing, should be used during all welding operations.

Where arc welding is carried on regularly in a building, the walls of the welding bay should be painted with a non-reflecting colour to prevent reflected glare. If this is not possible, movable screens should be provided around the place where welding is being carried out.

Appropriate protective clothing required for any welding operation will vary with the size, nature and location of the work to be performed. Flame-proof aprons made of leather, asbestos or other suitable material may also be desirable as protection against radiated heat and sparks. All clothing should be reasonably free from oil or grease. It is good practice to see that sleeves and collars are kept buttoned so that sparks may not get lodged in them. Even trousers and overalls should not be turned up at the bottom. Shoes should be worn preferably with fire-resistant leggings and should not be low cut. In production work, a sheet metal screen in front of the worker's legs provides further protection against sparks and molten metal in cutting operations

Ventilation is a prerequisite while working in confined spaces. If a welder has to enter a confined space through a manhole or other opening, means should be provided for quickly removing him in case of an emergency. When the welding operations are completed, the welder should mark the hot metal or provide some means of warning to indicate that the metal is hot.

No welding, cutting or other hot work should be performed on used drums, barrels, tanks or other containers until they have been cleaned completely. It should be made sure that there are no combustible materials nor any substances, such as petrol, spirit, greases, tars, acids or other materials, which, when subjected to heat might produce combustible toxic vapours. If this elementary precaution is not observed, there is every likelihood of both the welder and the welded drum being blown up in the air when welding is started.

In metal-arc welding, fumes are always given off from the coating of the electrode during welding. In the case of normal mild steel electrodes, these fumes have been proved, over many years, to be harmless. However, where electrode coatings contain fluorides, as in the case of low-hydrogen electrodes, and some austenitic steels, nickel, monel metal, cast iron and other non-ferrous metal electrode coatings, the fumes, if present in any great concentration, may prove harmful. Additional fumes may be given off by the oxidization of the metal by the atmosphere. Also, where zinc is present, either as a galvanized coating on steel sheet or in the form of brass, toxic fumes are produced by the heat of the arc causing the volatilization of zinc. Paint, when heated, may give off obnoxious fumes. It is, therefore, desirable that adequate ventilation for the operator should always be provided and where necessary an effective fume extraction system installed.

A welder wearing goggles or helmet is virtually blind to his surroundings and, when using a hand screen (or shield) he has both hands occupied. These two facts make it essential to provide table platforms which will give easy access to all welding operations especially in the field or heights on buildings. Protection against wind and weather is essential not only for affording comfort to operators but also for good workmanship, but also to prevent any welding being done on wet surfaces, which may produce defective welds.

SECTION 11

COST ESTIMATING AND ECONOMICS OF WELDING

11.1 Introduction

In every industrial operation, estimating and costing play a significant role, as the aim of an undertaking is to accomplish a job at the lowest possible cost consistent with efficiency and other considerations. This principle equally applies to fabrication and reclamation by welding.

An estimate is only an intelligent anticipation of the actual cost of the finished job. It is, however, possible for one to arrive at an estimated cost which may bear a close relationship to the actual cost from a thorough knowledge of all the factors that go to make up the cost and how these factors may be controlled under individual workshop conditions.

The total cost of a welded fabrication is made up of the following heads:

a) *Material Cost* involving the cost of all basic materials, such as steel sheets, plates, rolled sections, forgings, casting, etc, as may be used;

b) *Fabrication Cost* involving cost of (1) preparation, (2) welding, and (3) finishing, as detailed below:

  1) *Preparation cost* involving cost of material, handling, cutting, machining, or shearing plates or sections; preparing the edges for welding, forming, fitting up, positioning; labour for these operations, etc;

  2) *Welding cost* involving cost of electrodes, power consumed, welding labour, etc; and

  3) *Finishing cost* involving cost of all post-welding work, such as machining, grinding, sand-blasting, pickling, heat-treatment, painting, etc, and labour involved in carrying out these operations;

c) *Overhead Cost* involving all other costs, such as office and supervisory expenses, lighting, depreciation on capital, etc, which are not to be directly charged to a job.

It will be apparent from the foregoing that estimating and costing is a very specialized subject, and that it is beyond the scope of welders. Nevertheless, it is desirable that the welders should be familiar with the good and bad practices, so that they take steps in their own sphere of activity with a view to achieving economy in the cost of fabrication.

The effects of labour accomplishment and poor practices on the total cost respectively are illustrated in Fig. 100 and 101.

In this context, some guidance is being given to the welders in this Section as to how and why should they adhere to the good practices, so that welding costs may be controlled within those estimated.

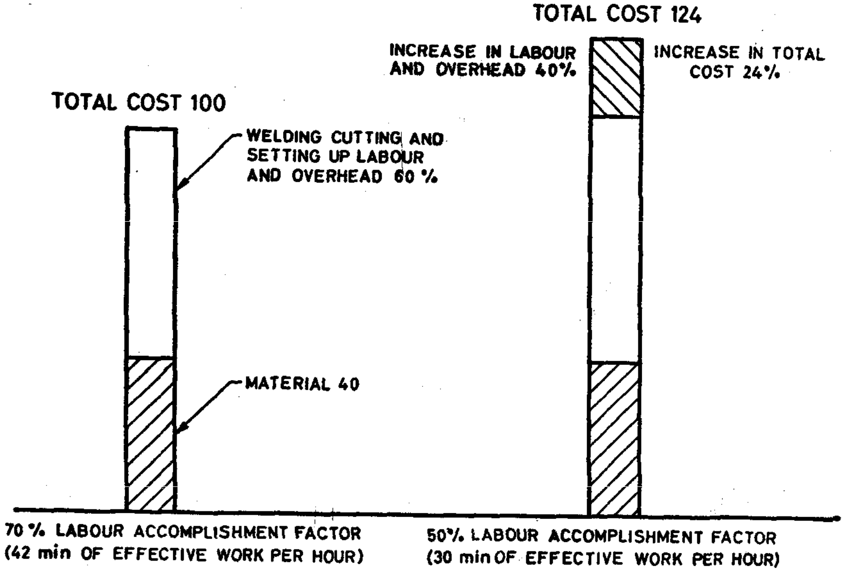


FIG. 100 LABOUR ACCOMPLISHMENT FACTOR

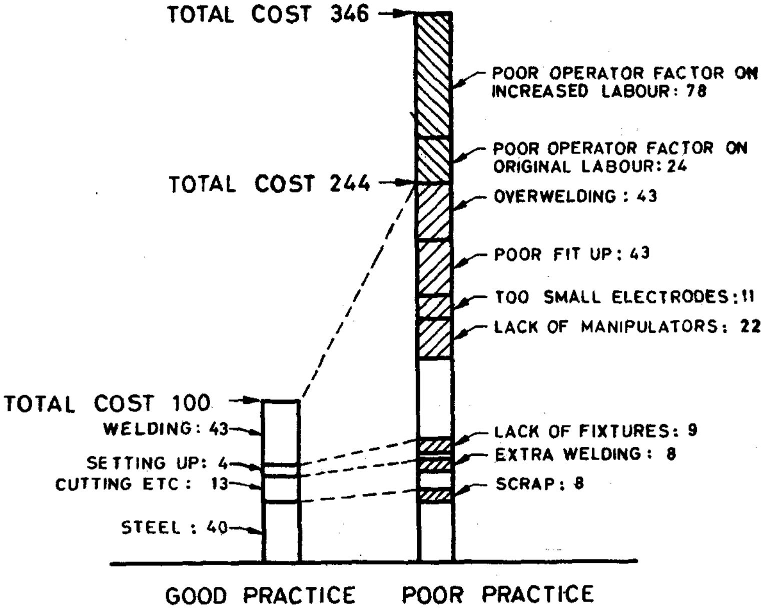
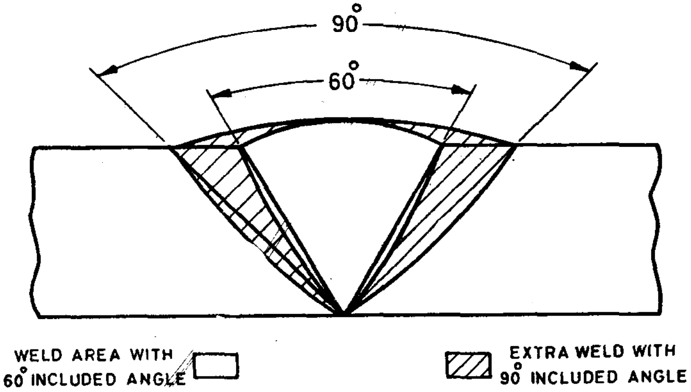


FIG. 101 CUMULATIVE EFFECT OF POOR PRACTICES ON COST

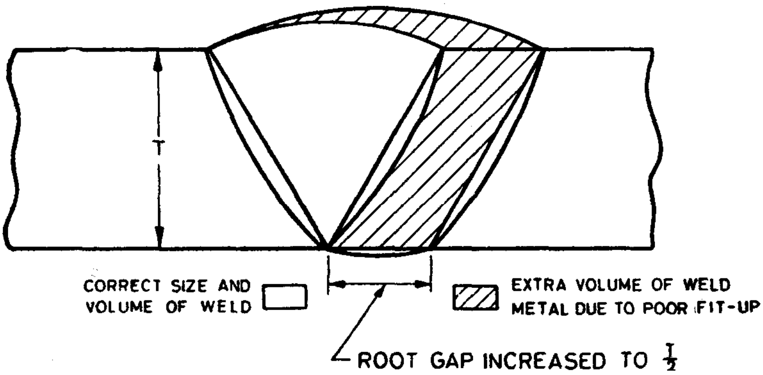
11.2 Preparation Cost

Welders should ensure that the plates and sections are prepared for welding, either by machining or by flame cutting, in accordance with the recommendations of the design office.

When employing flame cutting, the welders should ensure that the nozzle size, oxygen and fuel gas pressures and the speed of cutting used are in accordance with those recommended by the manufacturer of the equipment, who normally provide these data with the equipment. They should also ensure that the plates or rolled sections are cut to the proper size. The effects of inaccurate edge preparation and poor fit-up resulting in extra welding and consequently additional welding cost are illustrated in Fig. 102 A and 102 B.


90°
60°
WELD AREA WITH 60° INCLUDED ANGLE
EXTRA WELD WITH 90° INCLUDED ANGLE

102A Butt Weld Made with Bevelled Edge: 60° Included Angle (Correct) and 90° Included Angle (Incorrect)


T
CORRECT SIZE AND VOLUME OF WELD
EXTRA VOLUME OF WELD METAL DUE TO POOR FIT-UP
ROOT GAP INCREASED TO ½

102B Effects of Poor Fit-Up in a Butt Weld: Extra Welding and Higher Cost

FIG. 102 EFFECTS OF INCORRECT EDGE PREPARATION AND POOR FIT-UP

From a knowledge of the consumption of oxygen and fuel gas for cutting of different thicknesses, cutting speeds possible, cost of gases, labour rates and accomplishment factor, it is possible to estimate and work out the cost of preparation.

11.3 Welding Cost

In determining the direct welding cost, the following factors are taken into consideration:

a) Cost of electrodes — this being dependent on the type and size of electrode and edge preparation employed;

b) Power consumed;

c) Speed of welding;

d) Welding labour cost and labour accomplishment factor; and

e) Position of welding.

Charts showing the electrode consumptions of various types of welded joints and for different positions of welding are available. These charts also give the time required to complete a unit length of joint at 100 percent duty factor.

If the labour accomplishment factor and labour rates are known it is possible to work out the cost of welding a given type of joint.

The cost of power consumed may be calculated from the labour accomplishment factor and from the currents used. The empirical formula used for this is given below:

$$\text{Power cost} = \frac{V \times A}{1\,000} \times \frac{T}{60} \times \frac{1}{E} \times \text{rate per unit}$$

where

V = voltage,

A = current in amperes,

T = welding time in minutes, and

E = efficiency of the machine.

that is

$$\text{Power cost per hour} = \frac{V \times A}{1\,000} \times \frac{1}{E} \times 0{\cdot}4 \times \text{rate per unit}$$

where, 0·4 is taken as the ratio of operating time to connected time.

NOTE 1 — Normally, E is assumed to be 0·6 while estimating cost of power in the case of welding transformer.

NOTE 2 — Normally, E is assumed to be 0·25 while estimating cost of power in the case of welding generator.

While it is possible to work this out in the case of a small workshop employing only one or two welding sets, it is not possible to do so in larger workshops, where electricity is being used for operating other machines also. In these workshops, the cost of power is estimated from a knowledge of anticipated power demand and price per unit.

It has been stated earlier in this section that welders should be familiar with the good practices, and adherence to these will result in low welding cost. Most important of these are detailed below:

a) Overwelding, that is, excessive build up in the case of butt welds and fillet welds larger than those specified, should always be avoided. It will be seen from Fig. 103 that by increasing the weld from 4 mm to 8 mm, the triangular volume of metal required has increased from 2 to 8. Thus an increase of 400 percent in weld volume results with an increase of 100 percent in weld size.

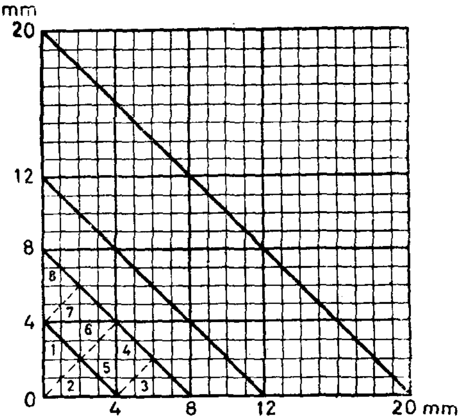


FIG. 103 COMPARATIVE SIZES OF 90° FILLETS

b) Ensure that the largest size of electrode compatible with the plate thickness is used. Use of smaller size of electrode will increase the cost of welding as more labour hours will be required to complete a weld of a given size and most often excessive distortion.

c) Use of proper welding current, as recommended by the manufacturer of the electrode for the given size, is essential. Use of currents beyond the range recommended will lead to excessive spatter loss and unsatisfactory weld; conversely, use of lower current than the recommended range will cause unsatisfactory fusion and consequently defective welds.

d) Avoid excessive stub end loss, ensuring that most of the usable portion of the electrode is used. The discarded portion of the electrode including the contact end, that is, bare part held in the electrode holder should never be more than 50 mm or preferably less. It will be seen from Fig. 104 that as the discarded length increases, the amount of filler metal utilized from an electrode decreases.

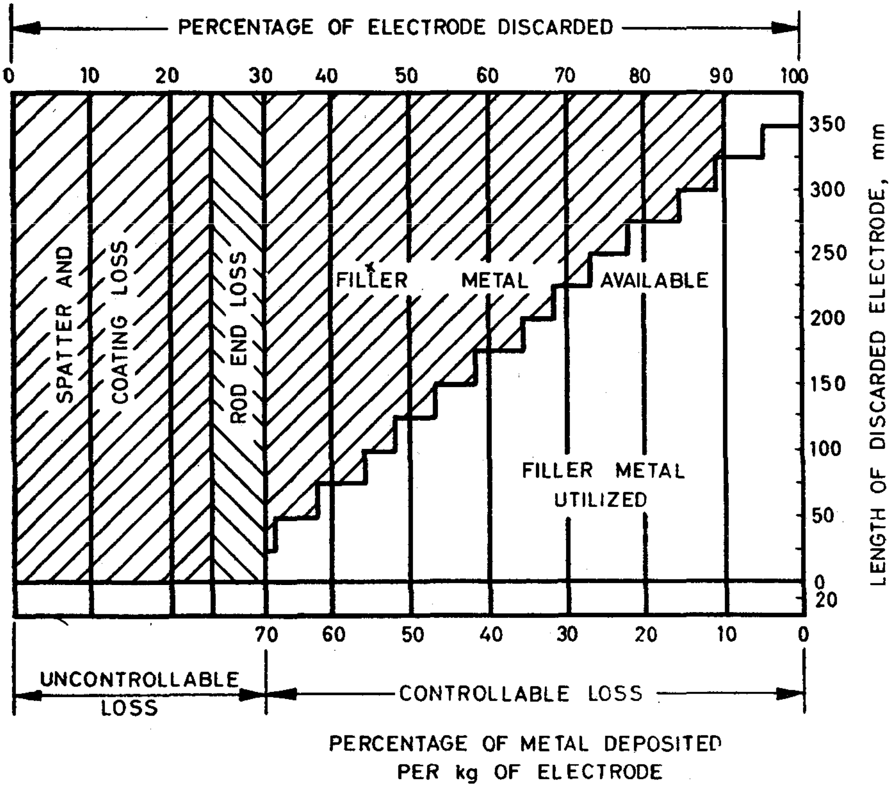


Fig. 104 Amount of Filler Metal Utilized for Different Discarded Lengths of Electrodes

e) The most convenient position of welding is in the downhand position. As a result of tests carried in various countries, it has been proved beyond doubt that the highest possible labour accomplishment factor and metal recovery rate have been possible when welding in the flat position than in any other position. Therefore, whenever possible, welding should be carried out in the flat position. A graphic form of the relative cost and speed of making a 10-mm fillet weld in various positions is illustrated in Fig. 105.

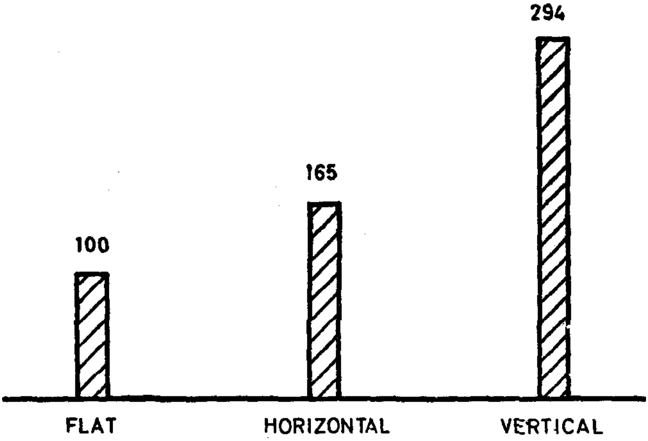


FIG. 105 RELATIVE COSTS AND SPEEDS FOR MAKING 10-mm FILLET WELDS IN DIFFERENT POSITIONS

Observance of these few simple rules by the welders will go a long way in achieving satisfactory welding cost.

11.4 Finishing Cost

Based on experience and the type of finishing required, the finishing cost for a particular welding job is estimated. But it should be noted that excessive welds or over welding, unsatisfactory welds and defective welding technique may lead to excessive finishing cost.

11.5 Overheads

This is an important item and there exists an elaborate and accurate system of computation and allocation of overhead expenses to the various stages of manufacturing process.

APPENDIX A

(*Section* 1, *Clause* 1.1)

DEFINITIONS OF COMMON WELDING TERMS

Automatic Welding — Fusion welding in which control of the welding operation is predominantly automatic.

Backing Ring — Backing in the form of a ring generally used in the welding of piping (*see* Fig. 106).

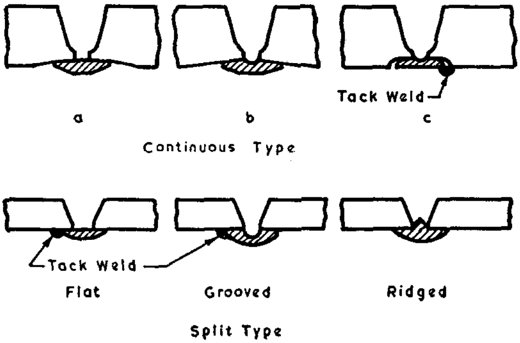


FIG. 106 TYPICAL BACKING RINGS

Backing Strip — A piece of metal placed at a root and penetrated by weld metal. It may remain as part of the joint or may be removed by machining or other means (*see* Fig. 107).

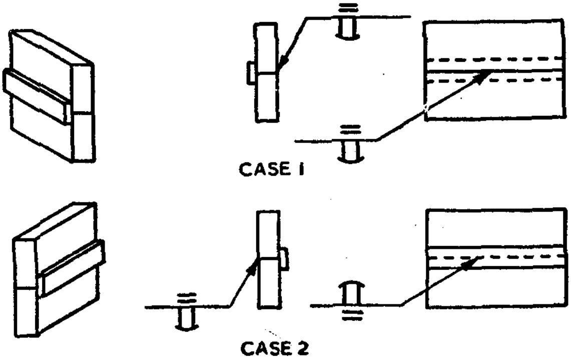


FIG. 107 BACKING STRIP

Flash Welding (Flash-Butt Welding) — A resistance-welding process wherein coalescence is produced, simultaneously, over the entire area of abutting surfaces, by the heat obtained from resistance to the flow of electric current between the two surfaces, and by the application of pressure after heating is substantially completed. Flashing and upsetting are accompanied by expulsion of metal from the joint.

Fusion Face — The portion of a surface, or of an edge, which is to be fused in making a fusion weld (*see* Fig. 108).

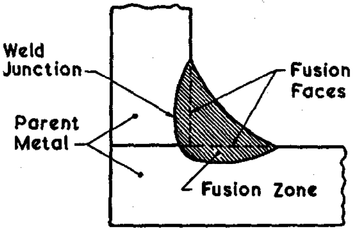


Fig. 108 Fusion Face

Fusion Welding — Any welding process in which the weld is made between metals in a state of fusion without hammering or pressure.

Fusion Zone — The portion of a weld in which parent metal has been fused (*see* Fig. 109).

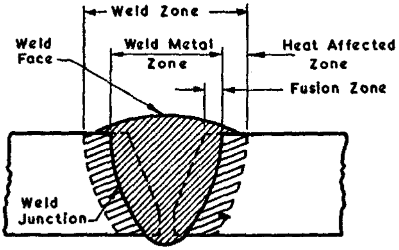
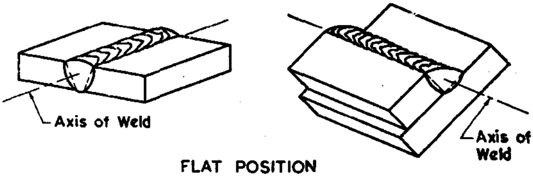


Fig. 109 Various Zones of a Typical Weld

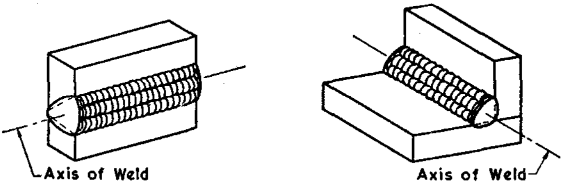
Heat-Affected Zone — Parent metal metallurgically affected by the heat of welding (or cutting), but neither melted nor made plastic (*see* Fig. 109).

Longitudinal Axis of Weld — A line through the length of a weld, perpendicular to the cross-section at its centre of gravity (*see* Fig. 110).

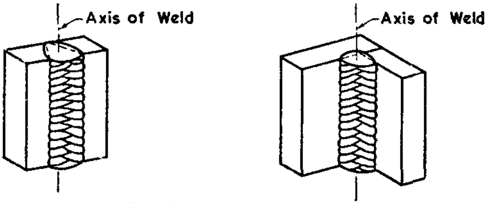
Pressure-Welding (Solid-Phase Welding) — Any welding process in which the weld is made by sustained pressure while the surfaces to be united are plastic.



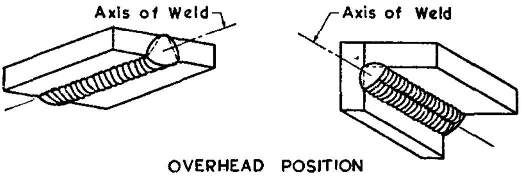
FLAT POSITION



HORIZONTAL-VERTICAL POSITION



VERTICAL POSITION



OVERHEAD POSITION

FIG. 110 LONGITUDINAL AXIS OF WELDS

Projection Welding — Resistance welding in which throughout the making of a weld the pressure is applied at a small projection or projections on one or more of the workpieces. The projections collapse during welding.

Resistance-Butt Welding — A resistance-welding process wherein weld is produced, simultaneously over the entire area of abutting surfaces or progressively along a joint, by the heat obtained from resistance to the flow of electric current through the area of contact of those surfaces. Pressure is applied before heating is started and is maintained throughout the heating period.

Resistance Welding (Upset Welding) — Welding in which pressure is applied between abutting surfaces at some stage in the process, and in which welding heat is produced by the electrical resistance at, and adjacent to, these surfaces during the passage of an electric current.

Roller-Spot Welding — Resistance welding in which pressure is applied continuously, and current impulsively, to produce a series of intermittent linear welds, the workpiece being between two electrode wheels, or between an electrode wheel and an electrode bar. The electrode wheels apply the pressure, and may be rotated continuously or stopped during the passage of current.

Seam Welding — Resistance welding in which pressure is applied continuously, and current impulsively, to produce a linear weld, the workpiece being between two electrode wheels, or between an electrode wheel and an electrode bar. The electrode wheels apply the pressure, and may be rotated continuously or stopped during the passage of current.

Semi-automatic Welding — Arc welding with equipment which controls only the filler metal feed. The advance of the welding is usually controlled manually.

Series-Spot Welding — Spot welding in which two or more welds are made simultaneously in electrical series (*see* Fig. 111).

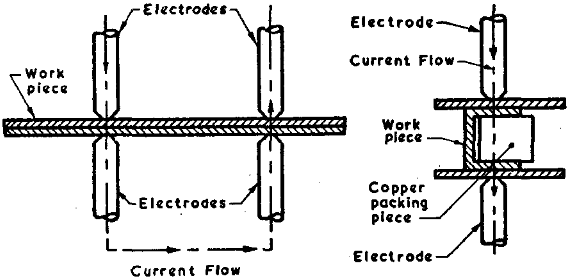


FIG. 111 EXAMPLES OF SERIES-SPOT WELDING

Spot Welding — A resistance-welding process wherein weld is produced by the heat obtained from resistance to the flow of electric current through the work parts held together under pressure by electrodes. The size and shape of the individually formed welds are limited primarily by the size and contour of the electrodes.

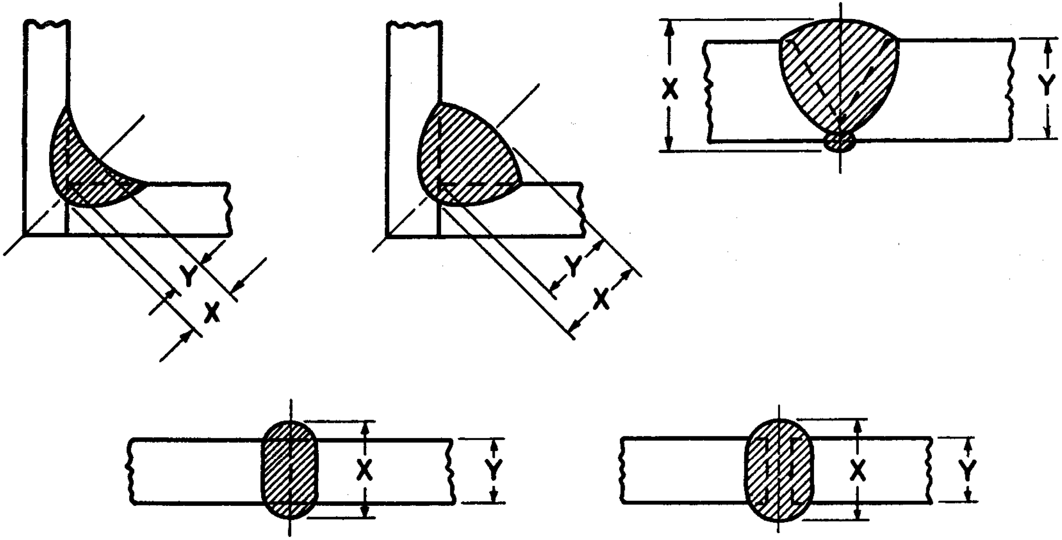
Surfacing — The deposition of filler metal by welding process on to a metal surface to obtain desired properties.

Throat Thickness — The minimum thickness of weld metal in a fusion weld measured as under (*see* Fig. 112):

a) *For a Fillet Weld or a V-, U-, J- or a Bevel-Butt Weld* — Along a line passing through the root.

b) *For a Close Square-Butt Weld* — In the plane of the abutting faces.

c) *For an Open Square-Butt Weld* — At the centre of the original gap in a plane parallel to the fusion faces.



X = Throat Thickness

Y = The Effective Throat Thickness as usually adopted

Fig. 112 Examples of Throat Thickness

Toe of Weld (Weld Edge) — The junction between the face of a weld and the parent metal.

Weld — A union between two pieces of metal at faces rendered plastic or liquid by heat or by pressure, or both. Filler metal may be used to effect the union.

Weld Cycle — The time required for one complete welding operation.

Weld Face — A surface of a fusion weld exposed on the side from which the weld has been made (*see* Fig. 113).

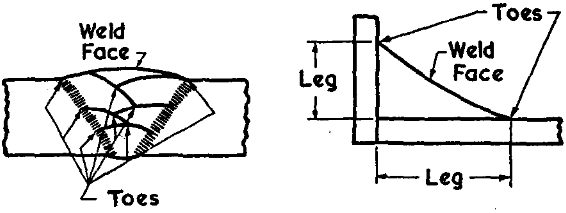


FIG. 113 EXAMPLES OF WELD FACES, TOES AND LEGS

Welding Current — The current flowing through the welding circuit during the making of a weld. In resistance-welding, the current used during pre-weld or post-weld intervals is excluded.

Weld Width — Distance between the toes of the weld.

Weld Zone — The sum of the weld-metal zone and the heat-affected zone (*see* Fig. 109).

APPENDIX B

(*Section* 2, *Clause* 2.2)

THEORY OF AC AND DC CURRENTS

The process of electrode welding consists of transmitting electrical energy from one point to another and then converting this energy into heat energy, which is used for joining metallic parts by fusion.

To transmit electrical energy, conductors and insulators are necessary. A conductor provides an easy path for the flow of the energy, and all metals come into the category of conductors. Some metals, however, are better conductors than others, and in this respect copper is a better conductor than iron or steel. The earth also is a conductor, although not a very good one like copper or aluminium.

The important insulating materials are cotton, paper, rubber and oil, and these for all practical purposes effectively resist the flow of electricity. It is thus possible to transfer electricity from one point to another by means of a conductor covered with an insulating material. To do this efficiently it is essential that the insulation covering is in good condition throughout its whole length, so as to confine the flow of electricity along the desired path. Bad insulation is a source of inefficiency often noticed in welding shops and should always be remedied to obtain best welding results. This may result in an unstable arc and fluctuations in the welding current.

Just as the flow of water or gas or any other fluid through a pipe requires pressure, electric current also requires pressure to flow along a conductor. The pressure required to make the current flow, is known as 'voltage'. The 'voltage' of a circuit may be measured with the help of an instrument called the voltmeter and this is expressed in volts.

The current is the rate at which electricity is flowing along a circuit, and this is measured in 'amperes', with the help of an instrument called the 'ammeter'.

Just as there is resistance to the flow of water or any other fluid in a pipe, there is resistance to the flow of electrical energy along a conductor. In the case of conductors carrying direct current (DC), the resistance offered to the flow of current is dependent on the length, sectional area, and the material used as a conductor. In practically all cases where it is desired that the current should flow with the minimum of resistance, copper and aluminium are used as conductors.

The resistance of a circuit to the flow of current is measured in units called 'ohms'. For a circuit carrying direct current (DC), a simple relationship exists among the pressure of the circuit, the current and the resistance of the circuit. This relationship is known as 'Ohm's law' and is expressed by the following expression:

$$\text{Resistance (Ohms)} = \frac{\text{Pressure (Volts)}}{\text{Current (Amperes)}}$$

In the case of circuits carrying alternating current (AC), the simple Ohm's law as given above, does not always apply. In this case, another form of resistance known as 'reactance' comes into play in addition to the pure and simple resistance mentioned earlier.

The terms 'alternating current' and 'direct current' are explained below:

There are many sources of electricity and the commonest one is known as the generator. The generator is driven by a prime mover, such as a water turbine, a steam turbine or an internal combustion engine. This generator works on what is known as the theory of electromagnetic induction. According to this theory, when a conductor is moved in magnetic field (an area where the influence of a magnet is prevalent), an electric current flows in it. So by keeping the conductor constantly in motion in a magnetic field, we can make the current flow continually. From physical considerations, making the conductor go round in a circle in a magnetic field is the simplest method of keeping it constantly in motion, and at the same time cover the least possible distance. Around a magnet, there are two different types of magnetic fields in existence, one due to its 'North Pole' and the other due to its 'South Pole'. Also, the intensity of the magnetic field itself varies depending on the proximity of the particular area to the magnet. Since, in its motion, the conductor is bound to move across magnetic fields of varying intensity and character, the value and the direction of its flow are bound to vary and this could be generally termed as *alternating current.* By proper design and construction of the generator, it may be so arranged that the value and the direction of the current mentioned above, do not vary in an erratic manner but follows a regular systematic cycle. In other words, the *alternating current* that we come across normally, attains the peak values on the *positive* as well as the *negative* sides and the zero values at regular intervals. In a '50 cycles' supply, the current attains the peak value on the *positive* sides (as also the peak value on the *negative* sides) and the zero, fifty times a second. This periodicity of the current is known as '*frequency*'.

Such an alternating current may not be useful for all purposes. So, by suitably modifying the machine that generates electricity, it is possible to generate a current which is unidirectional (that is, flows in one direction only) and of constant value. Such a current is known as a '*direct current*' or '*continuous current*', since it flows continuously in one direction only.

In the case of direct current, and also in case when the 'reactance' is zero in alternating current, the voltage and the current go hand in hand. But when the 'reactance' is present, the current and the voltage may become out of step with each other, and the current may 'lag' behind or 'lead', the voltage. When this happens, not all the electrical energy will be utilized to do useful work, some of it will be lost in 'unproductive' work. The 'Power Factor' gives an indication of the degree of 'lag' or 'lead' of the current in relation to the voltage or in other words, it gives an idea as to the extent to which the electrical energy 'used up' is doing useful work. In the case of the alternating current where the current and the voltage are in step with each other as referred to above, the 'Power Factor' is said to be 'Unity'. In other cases, the power factor is specified as 0·8, 0·75, 0·6, etc, followed by either of the words 'lag' or 'lead', numericals indicating the degree of 'out-of-the-step' between the current and the voltage and the words 'lag' or 'lead' respectively indicating whether the current is lagging behind the voltage or leading the voltage.

It is possible to store energy but not power. As soon as energy is used it is termed 'power' or 'work'. A 'watt' is the unit of electric power and is a measure of the time-rate of conversion or transmission of energy. In the simple case of the Ohm's law, enunciated above, the relationship between the various electrical units could be summed up as below:

$$\text{Power (Watts)} = \text{Pressure (Volts)} \times \text{Current (Amperes)}$$

or

$$= \text{Resistance (Ohms)} \times \text{Current (Amperes)} \times \text{Current (Amperes)}$$

$$= \text{Resistance (Ohms)} \times \text{Current}^2 \text{ (Amperes)}$$

Electrical energy may be converted into heat energy and stored by virtue of temperature. The energy stored in high temperature may then be released and converted into useful work such as melting metal, as is the case in the welding process.

APPENDIX C

(*See* Foreword)

INDIAN STANDARDS ON WELDING

ISI has so far issued the following Indian Standards in the field of welding:

IS : 812-1957 GLOSSARY OF TERMS RELATING TO WELDING AND CUTTING OF METALS

IS : 813-1961 SCHEME OF SYMBOLS FOR WELDING (*Amended*)

IS : 814-1963 SPECIFICATION FOR COVERED ELECTRODES FOR METAL ARC WELDING OF MILD STEEL (*Revised*)

IS : 815-1956 CLASSIFICATION AND CODING OF COVERED ELECTRODES FOR METAL ARC WELDING OF MILD STEEL AND LOW ALLOY HIGH-TENSILE STEELS

IS : 816-1956 CODE OF PRACTICE FOR USE OF METAL ARC WELDING FOR GENERAL CONSTRUCTION IN MILD STEEL

IS : 817-1957 CODE OF PRACTICE FOR TRAINING AND TESTING OF METAL ARC WELDERS

IS : 818-1957 CODE OF PRACTICE FOR SAFETY AND HEALTH REQUIREMENTS IN ELECTRIC AND GAS WELDING AND CUTTING OPERATIONS

IS : 819-1957 CODE OF PRACTICE FOR RESISTANCE SPOT WELDING FOR LIGHT ASSEMBLIES IN MILD STEEL

*IS : 823-1964 CODE OF PROCEDURE FOR MANUAL METAL ARC WELDING OF MILD STEEL

IS : 1179-1957 SPECIFICATION FOR EQUIPMENT FOR EYE AND FACE PROTECTION DURING WELDING

IS : 1181-1957 QUALIFYING TESTS FOR METAL ARC WELDERS (ENGAGED IN WELDING STRUCTURES OTHER THAN PIPES)

IS : 1182-1957 GENERAL RECOMMENDATIONS FOR RADIOGRAPHIC EXAMINATION OF FUSION WELDED JOINTS

IS : 1261-1959 CODE OF PRACTICE FOR SEAM WELDING IN MILD STEEL

IS : 1278-1958 SPECIFICATION FOR FILLER RODS AND WIRES FOR GAS WELDING

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*Under print.

IS : 1323-1959 CODE OF PRACTICE FOR OXY-ACETYLENE WELDING FOR STRUCTURAL WORK IN MILD STEEL

IS : 1393-1961 CODE OF PRACTICE FOR TRAINING AND TESTING OF OXY-ACETYLENE WELDERS

IS : 1395-1964 SPECIFICATION FOR MOLYBDENUM AND CHROMIUM MOLYBDENUM LOW ALLOY STEEL ELECTRODES FOR METAL-ARC WELDING (*Revised*)

IS : 1442-1964 SPECIFICATION FOR COVERED ELECTRODES FOR THE METAL-ARC WELDING OF HIGH TENSILE STRUCTURAL STEEL (*Revised*)

APPENDIX D

(*See* Foreword)

EQUIVALENT fps VALUES OF METRIC VALUES USED IN THE HANDBOOK

Metric Units mm	*Nearest fps Equivalents* in. *or* SWG
0·25	0·010
1	$\frac{1}{32}$
1·5	$\frac{1}{16}$
1·6	16 SWG
2	14 SWG
2·4	$\frac{3}{32}$
2·5	12 SWG
3	$\frac{1}{8}$
3·2	10 SWG
4	8 SWG
4	$\frac{5}{32}$
5	$\frac{3}{16}$
5	6 SWG
6	4 SWG
6	$\frac{1}{4}$
6·35	$\frac{1}{4}$
7	$\frac{1}{4}$
8	$\frac{5}{16}$
9	$\frac{3}{8}$
10	$\frac{3}{8}$
10·7	0·424
11·5	0·450
12	$\frac{1}{2}$
12·5	$\frac{1}{2}$
12·7	$\frac{1}{2}$
13	$\frac{9}{16}$
13·5	$\frac{17}{32}$
16	$\frac{5}{8}$
20	$\frac{3}{4}$
22	$\frac{7}{8}$

Metric Units mm	*Nearest fps Equivalents* in. *or* SWG
25	1
30	$1\frac{3}{16}$
32	$1\frac{1}{4}$
38	$1\frac{1}{2}$
50	2
60	$2\frac{3}{8}$
75	3
150	6
225	9
300	12
cm/metre	*in./ft*
2	$\frac{1}{4}$
mm/metre	
4	$\frac{1}{16}$

Metric Units kg/mm^2	*Nearest fps Equivalents* tons/in.^{2}
31·0	20·0
41·0	26·0
44·0	28·0
48·0	30·5
52·0	33·0
55·0	35·0
56·0	35·5
60·0	38·0
67·0	42·5
95·0	60·0
kgf·m	*lbf·ft*
4·10	30·0
5·70	41·0
7·00	50·5
8·90	64·0
10·40	75·0

APPENDIX E

(*See* Foreword)

COMPOSITION OF STRUCTURAL WELDING SECTIONAL COMMITTEE, SMDC 15

The ISI Committees responsible for processing this handbook consist of the following:

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